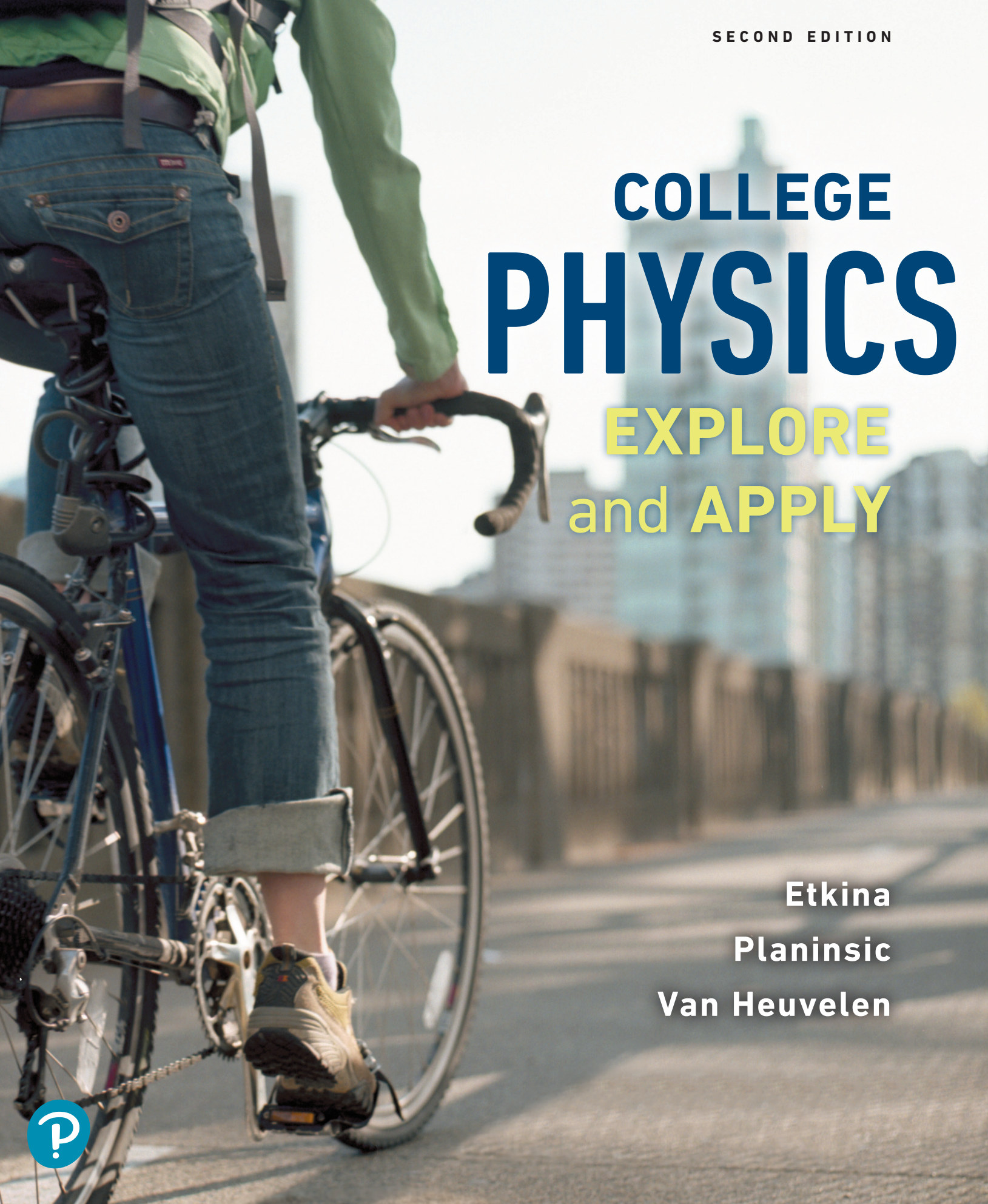


SECOND EDITION

COLLEGE PHYSICS

EXPLORE and APPLY

Etkina
Planinsic
Van Heuvelen

Help students learn physics by doing physics

Dear Colleague,

Welcome to the second edition of our textbook *College Physics: Explore and Apply* and its supporting materials (Mastering™ Physics, the *Active Learning Guide* (ALG), and our *Instructor's Guide*)—a coherent learning system that helps students **learn physics by doing physics**!

Experiments, experiments… Instead of being presented physics as a static set of established concepts and mathematical relations, students develop their own ideas just as physicists do: they *explore* and analyze **observational experiments**, identify patterns in the data, and propose explanations for the patterns. They then design **testing experiments** whose outcomes either confirm or contradict their explanations. Once tested, students *apply* explanations and relations for practical purposes and to problem solving.

A physics tool kit To build problem-solving skills and confidence, students master proven visual tools (representations such as motion diagrams and energy bar charts) that serve as bridges between words and abstract mathematics and that form the basis of our overarching problem-solving strategy. Our unique and varied problems and activities promote 21st-century competences such as evaluation and communication and reinforce our practical approach with photo, video, and data analysis and real-life situations.

A flexible learning system Students can work collaboratively on ALG activities in class (lectures, labs, and problem-solving sessions) and then read the textbook at home and solve end-of-chapter problems, or they can read the text and do the activities using Mastering Physics at home, then come to class and discuss their ideas. However they study, students will see physics as a living thing, a process in which they can participate as equal partners.

Why a new edition? With a wealth of feedback from users of the first edition, our own ongoing experience and that of a gifted new co-author, and changes in the world in general and in education in particular, we embarked on this second edition in order to refine and strengthen our experiential learning system. Experiments are more focused and effective, our multiple-representation approach is expanded, topics have been added or moved to provide more flexibility, the writing, layout, and design are streamlined, and all the support materials are more tightly correlated to our approach and topics.

Working on this new edition has been hard work, but has enriched our lives as we've explored new ideas and applications. We hope that using our textbook will enrich the lives of your students!

Eugenia Etkina

Gorazd Planinsic

Alan Van Heuvelen

"This book made me think deeper and understand better."

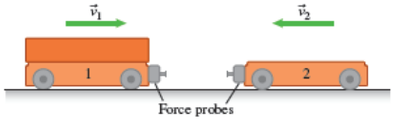
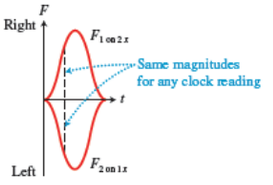
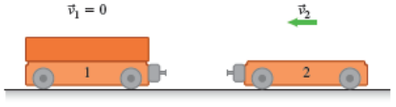
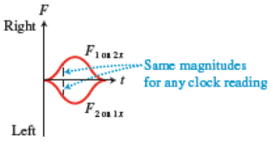
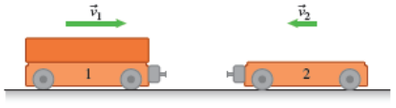
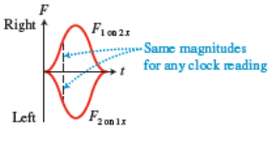
—student at *Horry Georgetown Technical College*

PEARSON

A unique and active learning approach promotes deep and lasting

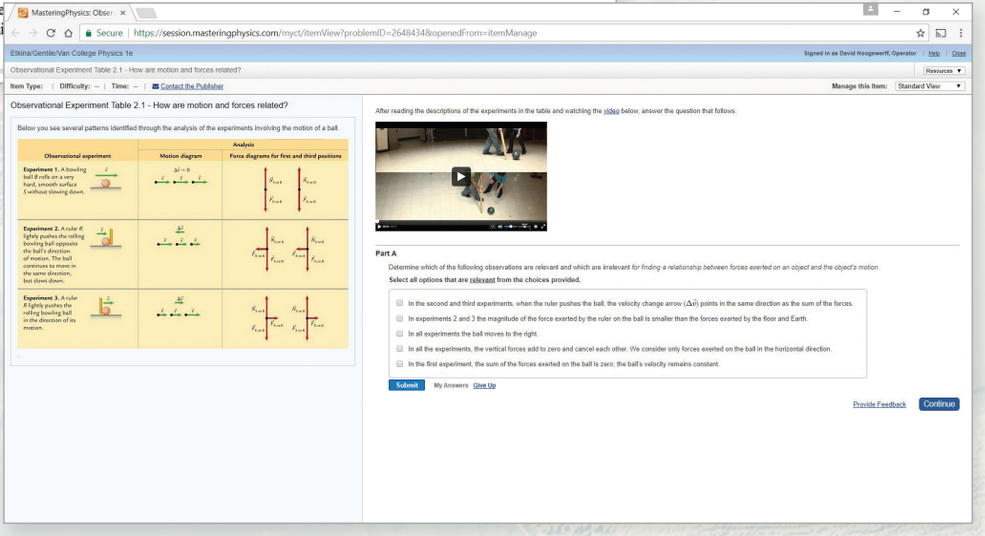
OBSERVATIONAL EXPERIMENT TABLE 3.6 Forces that two dynamics carts exert on each other

VIDEO OET 3.6

Observational experiment	Analysis
Experiment 1. Two carts of different masses move toward each other on a level track. A motion detector indicates their speed before the collision, and force probes record the forces exerted by each cart on the other. Before the collision: $m_1 = 1.0\ \text{kg}, v_{1x} = +2\ \text{m/s}$ $m_2 = 0.5\ \text{kg}, v_{2x} = -2\ \text{m/s}$ 	Because both carts changed velocities due to the collision, they must have exerted forces on each other. The computer recordings from the force probes show that the forces that the carts exert on each other vary with time and at each time have the same magnitude and point in opposite directions. Cart 1 exerts a force on cart 2 toward the right, and cart 2 exerts a force on cart 1 toward the left. 
Experiment 2. Cart masses and velocities before collision: $m_1 = 1.0\ \text{kg}, v_{1x} = 0\ \text{m/s}$ (at rest) $m_2 = 0.5\ \text{kg}, v_{2x} = -1\ \text{m/s}$ 	Although the forces that the carts exert on each other are smaller than in the first experiment, the magnitudes of the forces at each time are still the same. 
Experiment 3. Cart masses and velocities before collision: $m_1 = 1.0\ \text{kg}, v_{1x} = +2\ \text{m/s}$ $m_2 = 0.5\ \text{kg}, v_{2x} = -1\ \text{m/s}$ 	The same analysis applies. 
Pattern	
In each experiment, independent of the masses and velocities, the force that cart 1 exerted on cart 2 $\vec{F}_{1\text{ on }2}$ had the same magnitude as the force that cart 2 exerted on cart 1 $\vec{F}_{2\text{ on }1}$.	

UPDATED! Observational Experiment Tables and Testing Experiment Tables: Students must make observations, analyze data, identify patterns, test hypotheses, and predict outcomes. Redesigned for clarity in the second edition, these tables encourage students to explore science through active discovery and critical thinking, constructing robust conceptual understanding.

NEW! Digitally Enhanced Experiment Tables now include embedded videos in the Pearson eText for an interactive experience. Accompanying questions are available in Mastering Physics to build skills essential to success in physics.

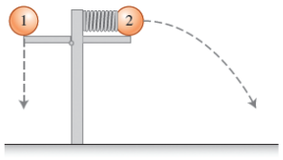

MasteringPhysics: Obser
Secure
https://session.masteringphysics.com/myct/itemView?problemID=2648434&openedFrom=itemManage
Etkina/Gentile/Van College Physics 1e
Signed in as David Hoogewerff, Operator
Help
Close
Observational Experiment Table 2.1 - How are motion and forces related?
Resources
Item Type:
Difficulty:
Time:
Contact the Publisher
Manage this Item:
Standard View
Observational Experiment Table 2.1 - How are motion and forces related?
Below you see several patterns identified through the analysis of the experiments involving the motion of a ball.
Observational experiment
Analysis
Motion diagram
Force diagrams for first and third positions
After reading the descriptions of the experiments in the table and watching the video below, answer the question that follows.
Part A
Determine which of the following observations are relevant and which are irrelevant for finding a relationship between forces exerted on an object and the object's motion.
Select all options that are relevant from the choices provided.
In the second and third experiments, when the ruler pushes the ball, the velocity change arrow ($\Delta\vec{v}$) points in the same direction as the sum of the forces.
In experiments 2 and 3 the magnitude of the force exerted by the ruler on the ball is smaller than the forces exerted by the floor and Earth.
In all experiments the ball moves to the right.
In all the experiments, the vertical forces add to zero and cancel each other. We consider only forces exerted on the ball in the horizontal direction.
In the first experiment, the sum of the forces exerted on the ball is zero; the ball's velocity remains constant.
Submit
My Answers
Give Up
Provide Feedback
Continue

conceptual understanding of physics and the scientific process

TESTING
EXPERIMENT TABLE 4.6

Testing the independence of horizontal and vertical motions

VIDEO TET 4.6

Testing experiment	Prediction	Outcome
At time zero, ball 1 is dropped. Simultaneously, ball 2 is shot horizontally when a compressed spring is released. Which ball hits the surface first? 	Both balls start with zero initial vertical speed; thus their vertical motions are identical. Since we think that the vertical motion is independent of the horizontal motion, we predict that they will land at the same time.	When we try the experiment, the balls do land at the same time.

Conclusion

The outcome supports the hypothesis that horizontal and vertical motions are independent of each other.

> *"I like that the experiment tables... explain in detail why every step was important."*
>
> —student at *Mission College*

EXPANDED! Experiment videos and photos created by the authors enhance the active learning approach. Approximately 150 photos and 40 videos have been added to the textbook, as well as embedded in the Pearson eText, and scores more in the *Active Learning Guide* (ALG).

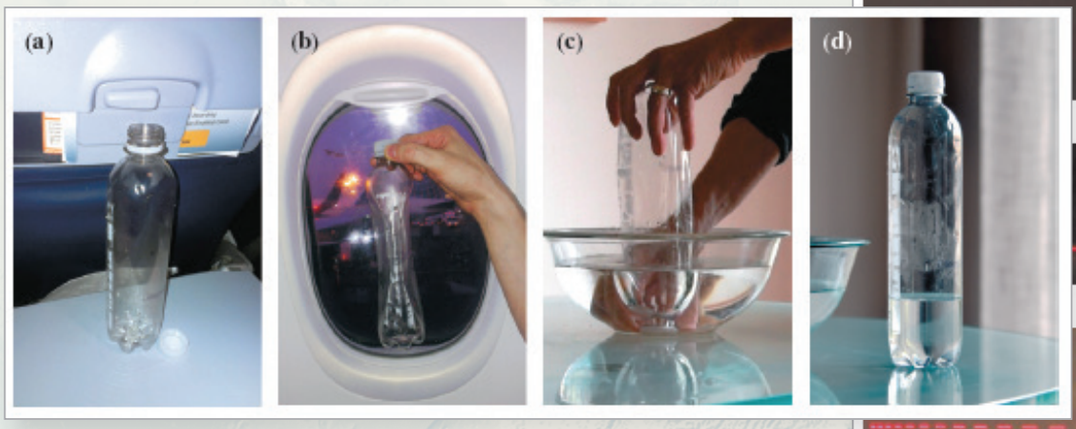
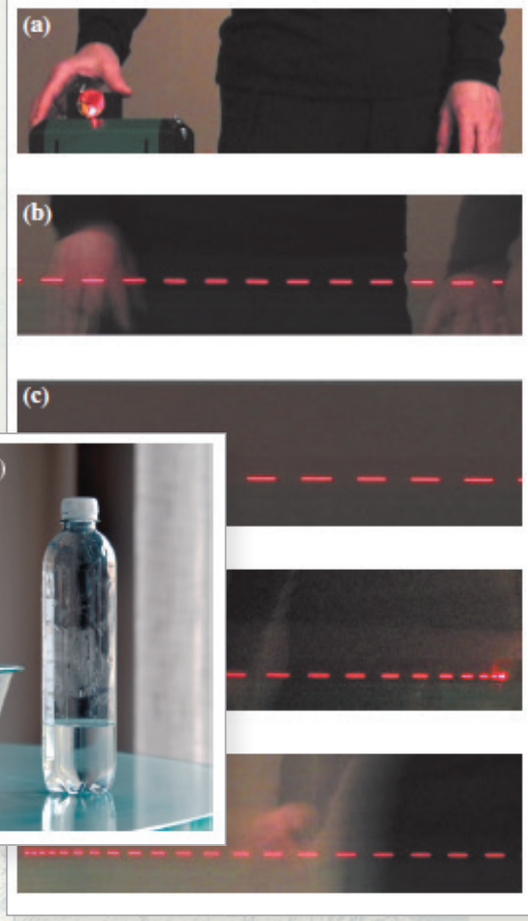


FIGURE 2.2 Long-exposure photographs of a moving cart with a blinking LED.



A wealth of practical and consistent guidance, examples, and opportunities

PROBLEM-SOLVING STRATEGY 14.1 Applying Bernoulli's equation

Sketch and translate

- Sketch the situation. Include an upward-pointing y-coordinate axis. Choose an origin and positive direction for the coordinate axis.
- Choose points 1 and 2 at positions in the fluid where you know the pressure/speed/position or that involve the quantity you are trying to determine.
- Choose a system.

Simplify and diagram

- Identify any assumptions you are making. For example, can we assume that there are no resistive forces exerted on the flowing fluid?
- Construct a Bernoulli bar chart.

Represent mathematically

- Use the sketch and bar chart to help apply Bernoulli's equation.
- You may need to combine Bernoulli's equation with other equations, such as the equation of continuity $Q = v_1A_1 = v_2A_2$ and the definition of pressure $P = F/A$.

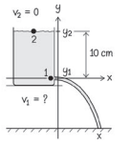
Solve and evaluate

- Solve the equations for an unknown quantity.
- Evaluate the results to see if they are reasonable (the magnitude of the answer, its unit, how the answer changes in limiting cases, and so forth).

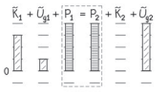
EXAMPLE 14.2 Removing a tack from a water bottle

What is the speed with which water flows from a hole punched in the side of an open plastic bottle? The hole is 10 cm below the water surface.

- Choose the origin of the vertical y-axis to be the location of the hole.
- Choose position 1 to be the place where the water leaves the hole and position 2 to be a place where the pressure, elevation, and water speed are known—at the water surface $y_2 = 0.10$ m. The pressure in Bernoulli's equation at both positions 1 and 2 is atmospheric pressure, since both positions are exposed to the atmosphere ($P_1 = P_2 = P_{atm}$).
- Choose Earth and the water as the system.



- Assume that no resistive forces are exerted on the flowing fluid.
- Assume that y_2 and y_1 stay constant during the process, since the elevation of the surface decreases slowly compared to the speed of the water as it leaves the tiny hole.
- Because the water at the surface is moving very slowly relative to the hole, assume that $v_2 = 0$.
- Draw a bar chart that represents the process.



- We see from the sketch and the bar chart that the speed of the fluid at position 2 is zero (zero kinetic energy density) and that the elevation is zero at position 1 (zero gravitational potential energy density). Also, the pressure is atmospheric at both 1 and 2. Thus

$$\tfrac{1}{2}\rho(0)^2 + \rho g y_2 + P_{atm} = P_{atm} + \tfrac{1}{2}\rho v_1^2 + \rho g(0)$$
$$\Rightarrow \rho g y_2 = \tfrac{1}{2}\rho v_1^2$$

- Solve for v_1:

$$v_1 = \sqrt{2gy_2}$$

Substituting for g and y_2, we find that

$$v_1 = \sqrt{2(9.8\ \text{m/s}^2)(0.10\ \text{m})} = 1.4\ \text{m/s}$$

- The unit m/s is the correct unit for speed. The magnitude seems reasonable for water streaming from a bottle (if we obtained 120 m/s it would be unreasonably high).

Try it yourself In the above situation the water streams out of the bottle onto the floor a certain horizontal distance away from the bottle. The floor is 1.0 m below the hole. Predict this horizontal distance using your knowledge of projectile motion. (Hint: Use Eqs. (4.7) and (4.8).)

Answer The equations yield a result of 0.63 m. However, if we were to actually perform this experiment with a tack-sized hole, the water would land short of our prediction because of resistive forces exerted by the hole on the water. In order to make the water land closer to 0.63 m from the bottle, we must increase the diameter of the hole. We discuss the effect of resistive forces on fluid flow later in the chapter.

A four-step problem-solving approach in worked examples consistently uses multiple representations to teach students how to solve complex physics problems. Students follow the steps of **Sketch & Translate, Simplify & Diagram, Represent Mathematically, Solve & Evaluate** to translate a problem statement into the language of physics, sketch and diagram the problem, represent it mathematically, solve the problem, and evaluate the result.

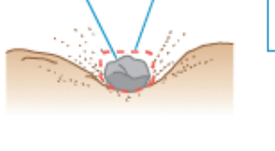
Physics Tool Boxes focus on a particular skill, such as drawing a motion diagram, force diagram, or work-energy bar chart, to help students master the key tools they will need to utilize throughout the course to analyze physics processes and solve problems, bridging real phenomena and mathematics.

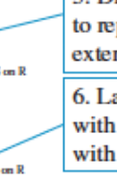
"It made me excited to learn physics! It has a systematic and easy-to-understand method for solving problems."

—student at *State University of West Georgia*

PHYSICS TOOL BOX 3.1 Constructing a force diagram

1. Sketch the situation (a rock sinking into sand).
2. Circle the system (the rock).
3. Identify external interactions:
   - The sand pushes up on the rock.
   - Earth pulls down on the rock.
4. Place a dot at the side of the sketch, representing the system.
5. Draw force arrows to represent the external interactions.
6. Label the forces with a subscript with two elements.





for practice help develop confidence and higher-level reasoning skills

56. * A frog jumps at an angle 30° above the horizontal. The origin of the coordinate system is at the point where the frog leaves the ground. Complete Table P4.55 by drawing check marks in the cells that correctly connect the quantities in the first column that describe the motion of the frog and the descriptions of what is happening to these quantities while the frog is moving. Consider the frog as a point-like object and assume that the resistive force exerted by the air is negligible.

TABLE P4.55

Physical quantity	Remains constant	Is changing	Increases only	Decreases only	Increases, then decreases	Decreases, then increases
x-coordinate magnitude						
y-coordinate magnitude						
Direction of velocity						
Magnitude of velocity						
Direction of acceleration						
Magnitude of acceleration						

29. * Your friend Devin has to solve the following problem: "You have a spring with spring constant k. You compress it by distance x and use it to shoot a steel ball of mass m into a sponge of mass M. After the collision, the ball and the sponge move a distance s along a rough surface and stop (see Figure P7.29). The coefficient of friction between the sponge and the surface is μ. Derive an expression that shows how the distance s depends on relevant physical quantities."

FIGURE P7.29

Devin derived the following equation:

$$s = \frac{kmx^2}{2(m+M)^2 g\mu}$$

Without deriving it, evaluate the equation that [illegible] reasonable? How do you know?

NEW! Problem types include multiple choice with multiple correct answers, find-a-pattern in data presented in a video or a table, ranking tasks, evaluate statements/claims/explanations/measuring procedures, evaluate solutions, design a device or a procedure that meets given criteria, and linearization problems, promoting critical thinking and deeper understanding.

59. * Jeff and Natalie notice that a rubber balloon, which is first in a warm room, shrinks when they take it into the garden on a cold winter day. They propose two different explanations for the observed phenomenon: (a) the balloon is slowly leaking; (b) the balloon shrinks due to decreased temperature while the pressure in the balloon remains constant (isobaric compression). In order to test their proposed explanations, Jeff and Natalie perform three consecutive experiments: they measure the volume of the balloon and the temperature of the air near the balloon (1) in the room, (2) in the garden, and (3) again in the room. Their measurements, including uncertainties, are presented in the table below.

Exp. #	Location	Temperature	Volume of the balloon
1	Room	26.2 °C ± 0.1 °C	7500 cm³ ± 400 cm³
2	Garden	−15.3 °C ± 0.1 °C	6400 cm³ ± 400 cm³
3	Room	26.2 °C ± 0.1 °C	7300 cm³ ± 400 cm³

Based on the data, can Jeff and Natalie reject any of their hypotheses? Explain. Make sure you include uncertainties in your answer.

"It helps break down the problems, which makes them look less daunting when compared to paragraphs of explanations. It is very straightforward."

—student at *Case Western Reserve University*

Pedagogically driven design and content changes

NEW! A fresh and modern design with a more transparent hierarchy of features and navigation structure, as well as an engaging chapter opener page and streamlined chapter summary, result in a more user-friendly resource, both for learning and for reference.

12

Gases

- Why does a plastic bottle left in a car overnight look crushed on a chilly morning?
- How hard is air pushing on your body?
- How long can the Sun shine?

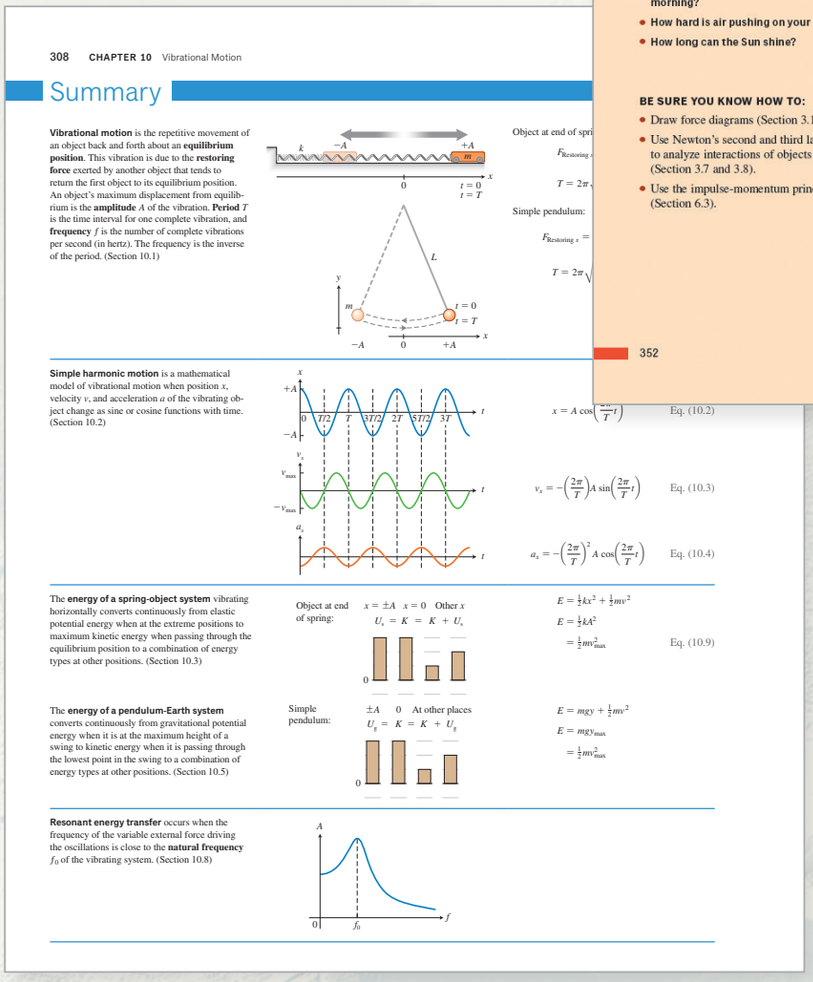
When you inflate the tires of your bicycle in a warm basement in winter, they tend to look a bit flat when you take the bike outside. The same thing happens to a basketball—you need to pump it up before playing outside on a cold day. An empty plastic bottle left in a car looks crushed on a chilly morning. What do all those phenomena have in common, and how do we explain them?

BE SURE YOU KNOW HOW TO:

- Draw force diagrams (Section 3.1).
- Use Newton's second and third laws to analyze interactions of objects (Section 3.7 and 3.8).
- Use the impulse-momentum principle (Section 6.3).

IN CHAPTER 11, we learned that sound propagates due to the compression and decompression of air. But what exactly is being compressed? To answer this question and the ones above, we need to investigate what makes up a gas and how certain properties of gases can change.

352



308 **CHAPTER 10** Vibrational Motion

Summary

Vibrational motion is the repetitive movement of an object back and forth about an **equilibrium position**. This vibration is due to the **restoring force** exerted by another object that tends to return the first object to its equilibrium position. An object's maximum displacement from equilibrium is the **amplitude** A of the vibration. **Period** T is the time interval for one complete vibration, and **frequency** f is the number of complete vibrations per second (in hertz). The frequency is the inverse of the period. (Section 10.1)

Simple harmonic motion is a mathematical model of vibrational motion when position x, velocity v_x, and acceleration a_x of the vibrating object change as sine or cosine functions with time. (Section 10.2)

$$x = A\cos\left(\frac{2\pi}{T}t\right) \qquad \text{Eq. (10.2)}$$

$$v_x = -\left(\frac{2\pi}{T}\right)A\sin\left(\frac{2\pi}{T}t\right) \qquad \text{Eq. (10.3)}$$

$$a_x = -\left(\frac{2\pi}{T}\right)^2 A\cos\left(\frac{2\pi}{T}t\right) \qquad \text{Eq. (10.4)}$$

The **energy of a spring-object system** vibrating horizontally converts continuously from elastic potential energy when at the extreme positions to maximum kinetic energy when passing through the equilibrium position to a combination of energy types at other positions. (Section 10.3)

$$E = \tfrac{1}{2}kx^2 + \tfrac{1}{2}mv^2$$
$$E = \tfrac{1}{2}kA^2$$
$$= \tfrac{1}{2}mv_{max}^2 \qquad \text{Eq. (10.9)}$$

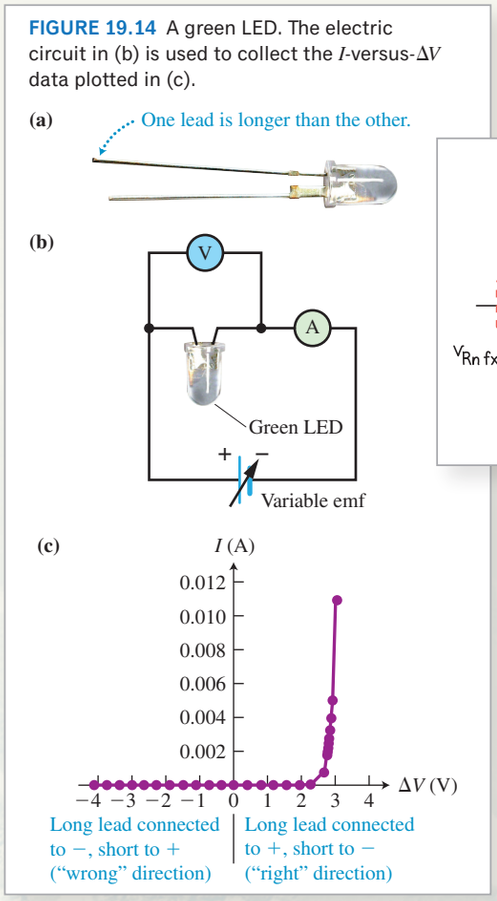
The **energy of a pendulum-Earth system** converts continuously from gravitational potential energy when it is at the maximum height of a swing to kinetic energy when it is passing through the lowest point in the swing to a combination of energy types at other positions. (Section 10.5)

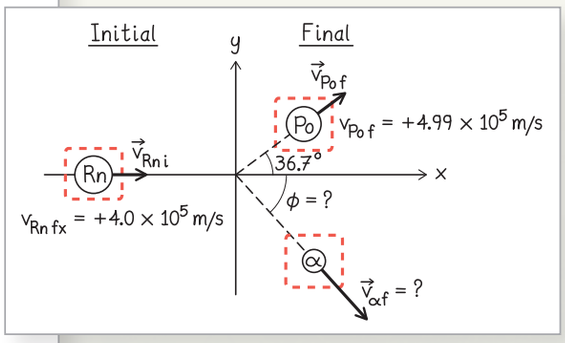
$$E = mgy + \tfrac{1}{2}mv^2$$
$$E = mgy_{max}$$
$$= \tfrac{1}{2}mv_{max}^2$$

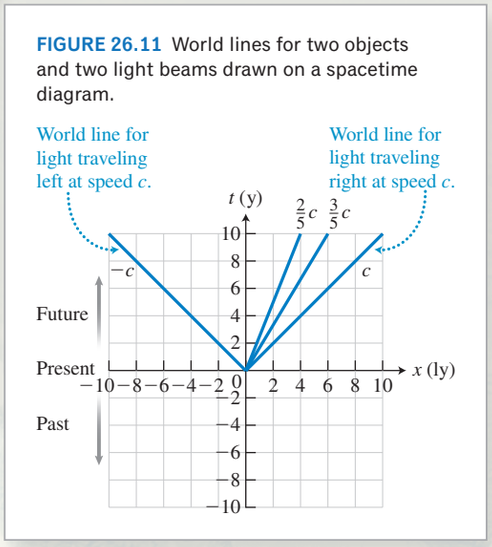
Resonant energy transfer occurs when the frequency of the variable external force driving the oscillations is close to the **natural frequency** f_0 of the vibrating system. (Section 10.8)

REVISED! Streamlined text, layout, and figures throughout the book enhance the focus on central themes and topics, eliminating extraneous detail, resulting in **over 150 fewer pages** than the first edition and allowing students to study more efficiently.

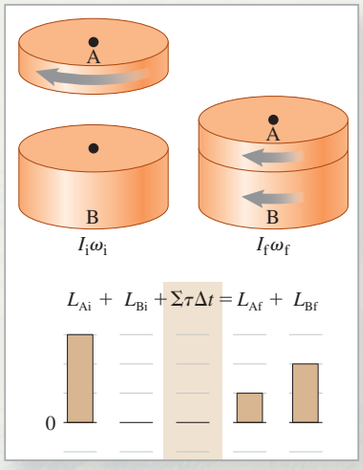
enhance ease of use for students and instructors alike







NEW, REVISED, and EXPANDED! **Topics** include capacitors, AC circuits, LEDs, friction, 2-D collisions, energy, bar charts for rotational momentum and nuclear energy, ideal gas processes, thermodynamic engines, semiconductors, velocity selectors, and spacetime diagrams in special relativity.



NEW! Integration of vector arithmetic into early chapters helps students develop vector-related skills in the context of learning physics. **Earlier placement of waves and oscillations** allows instructors to teach these topics with mechanics if preferred. Coverage with optics is also possible.

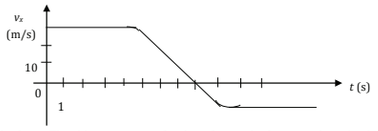
A flexible learning system adapts to any method of instruction

2.9.9 Evaluate the solution

Class: *Equipment per group: whiteboard and markers*

Discuss with your group: Identify any errors in the proposed solution to the following problem and provide a corrected solution if there are errors.

Problem: Use the graphical representation of motion to determine how far the object travels until it stops.

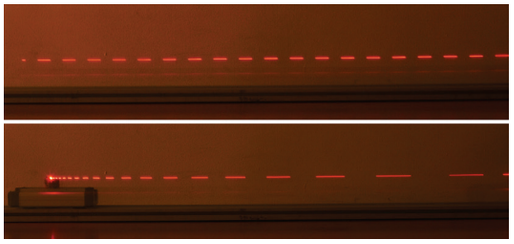


Proposed solution The object was at rest for about 5 seconds, then started moving in the negative direction and stopped after about 9 seconds. During this time its position changed from 30 m to – 10 m, so the total distance that it traveled was 40 m.

2.9.10 Observe and analyze

Class: *Equipment per group: whiteboard and markers*

Collaborate together with your group to figure this out: The figure below shows long exposure photos of two experiments with a blinking LED that was fixed on a moving cart. In both cases the cart was moving from right to left. The duration of the ON and OFF time for LED is 154 ms and the length of the cart is 17 cm. a) Specify the coordinate system and draw a qualitative velocity-time graph for the motion of the cart in both experiments; b) estimate the speed of the cart in the first experiment. Both photos were obtained from the same spot and with the same settings. Indicate any assumptions that you made.



Etkina, Brookes, Planinsic, Van Heuvelen COLLEGE PHYSICS *Active Learning Guide,* 2/e © 2019 Pearson Education, Inc.

REVISED! The **Active Learning Guide** aligns with the textbook's chapters and supplements the knowledge-building approach of the textbook with activities that provide opportunities for further observation, testing, sketching, and analysis as well as collaboration, scientific reasoning, and argumentation. The *Active Learning Guide* can be used in class for individual or group work or assigned as homework and is now better integrated with the text. Now available via download in the Mastering Instructor Resource Center and customizable in print form via Pearson Collections.

2

Kinematics: Motion in One Dimension

In Chapter 2, students will learn to describe motion using sketches, motion diagrams, graphs, and algebraic equations. The chapter subject matter is broken into four parts:

I. *What is motion and how do we describe it qualitatively?*
II. *Some of the quantities used to describe motion and a graphical description of motion*
III. *Use of the above to describe constant velocity and constant acceleration motion*
IV. *Developing and using the skills needed to analyze motion in real processes*

For each part, we provide examples of activities that can be used in the classroom, brief discussions of why we introduce the content in a particular order and use of these activities to support the learning, and common student difficulties.

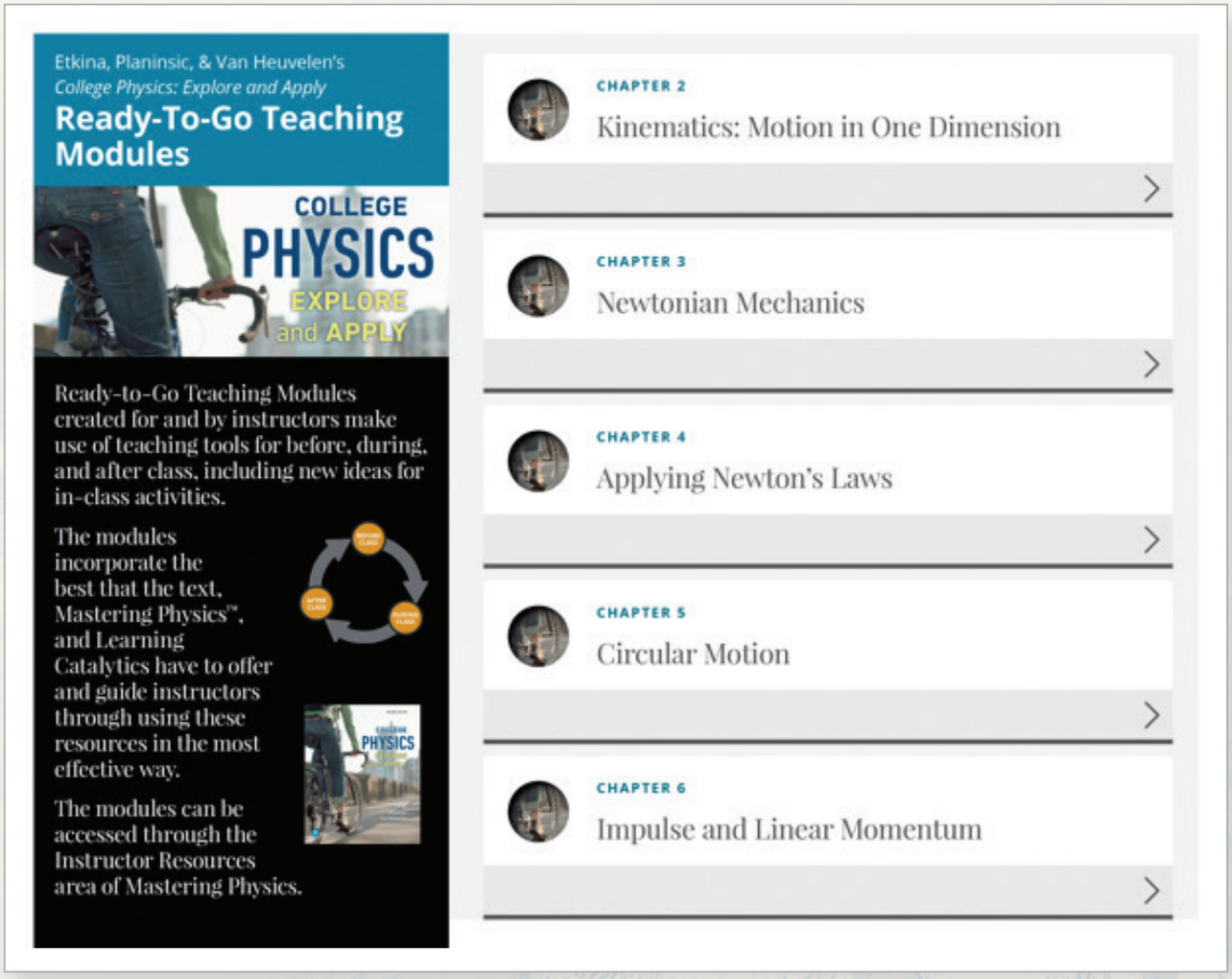
Chapter subject matter	Related textbook section	ALG activities	End-of-chapter questions and problems	Videos
What is motion and how do we describe it qualitatively?	2.1, 2.2	2.1.1–2.1.6, 2.2.1–2.2.4	Problems 1, 3	OET 2.1

> *"It is much easier to understand a concept when you can see it in action, and not just read it."*
>
> —student at *San Antonio College*

The **Instructor's Guide** provides key pedagogical principles of the textbook and elaborates on the implementation of the methodology used in the textbook, providing guidance on how to integrate the approach into your course.

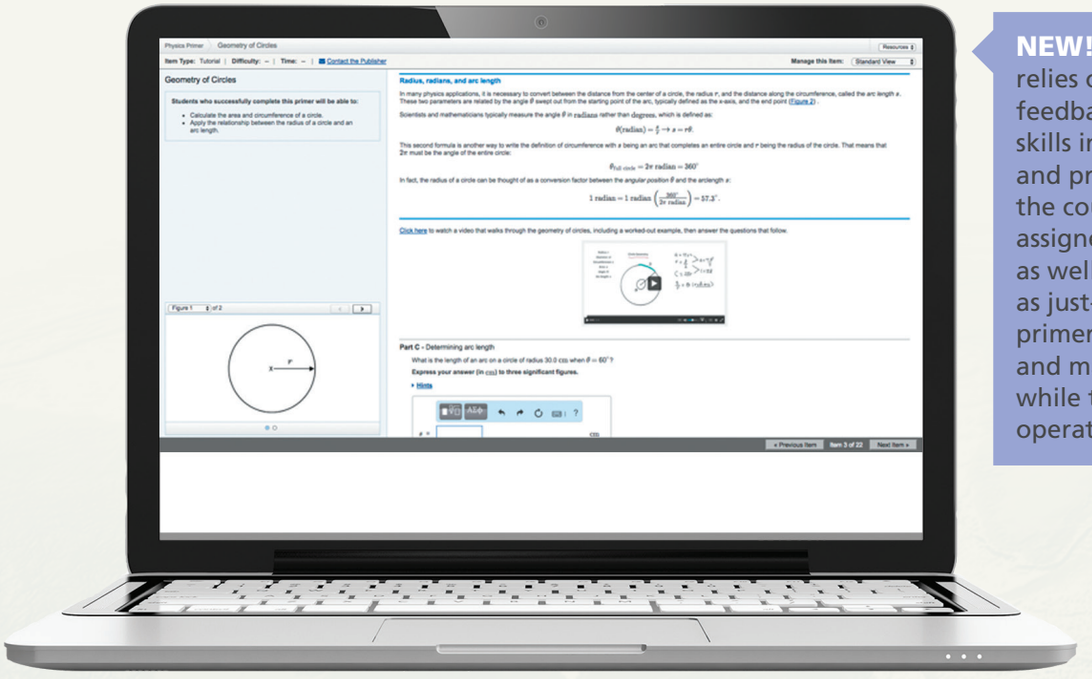
and provides tools for easy implementation

NEW! Ready-to-Go Teaching Modules created for and by instructors make use of teaching tools for before, during, and after class, including new ideas for in-class activities. The modules incorporate the best that the text, Mastering Physics, and Learning Catalytics have to offer and guide instructors through using these resources in the most effective way. The modules can be accessed through the Instructor Resources area of Mastering Physics and as pre-built, customizable assignments.


Etkina, Planinsic, & Van Heuvelen's
College Physics: Explore and Apply
Ready-To-Go Teaching Modules
COLLEGE
PHYSICS
EXPLORE and APPLY
Ready-to-Go Teaching Modules created for and by instructors make use of teaching tools for before, during, and after class, including new ideas for in-class activities.
The modules incorporate the best that the text, Mastering Physics™, and Learning Catalytics have to offer and guide instructors through using these resources in the most effective way.
The modules can be accessed through the Instructor Resources area of Mastering Physics.
CHAPTER 2
Kinematics: Motion in One Dimension
CHAPTER 3
Newtonian Mechanics
CHAPTER 4
Applying Newton's Laws
CHAPTER 5
Circular Motion
CHAPTER 6
Impulse and Linear Momentum

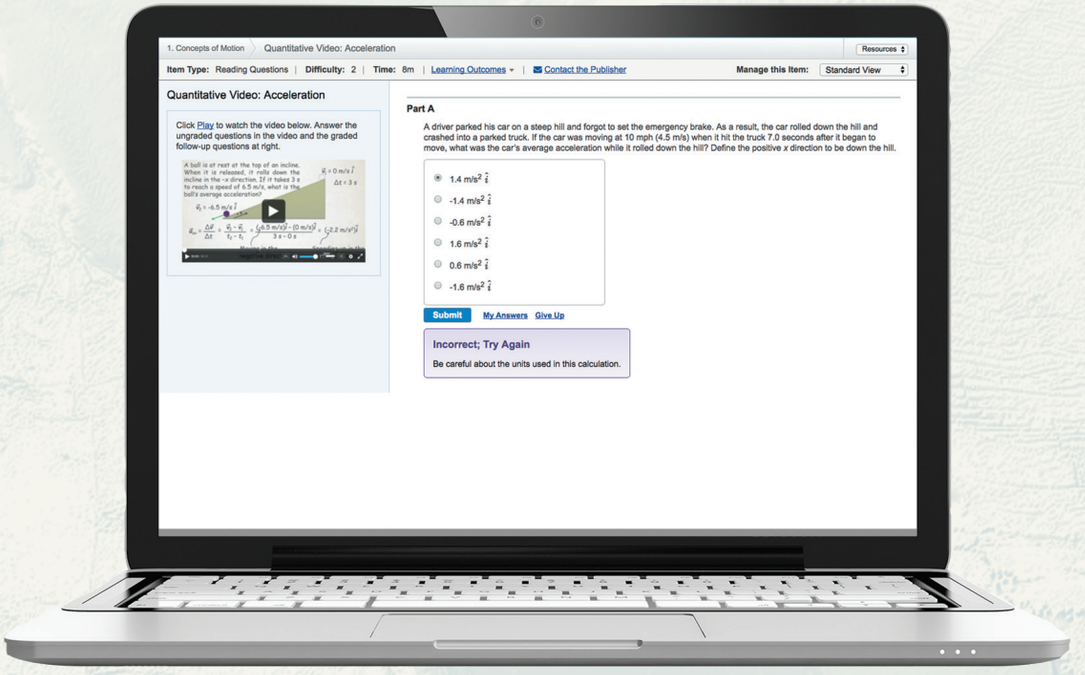
Mastering Physics

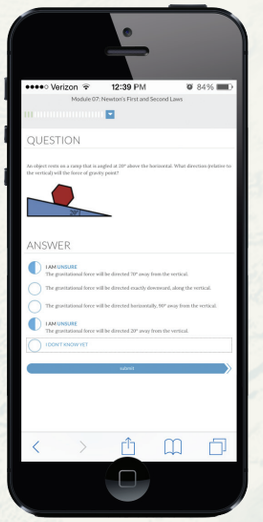
Build a basic understanding of physics principles and math skills



NEW! The Physics Primer relies on videos, hints, and feedback to refresh students' math skills in the context of physics and prepare them for success in the course. These tutorials can be assigned before the course begins as well as throughout the course as just-in-time remediation. The primer ensures students practice and maintain their math skills, while tying together mathematical operations and physics analysis.

Interactive Animated Videos provide an engaging overview of key topics with embedded assessment to help students check their understanding and to help professors identify areas of confusion. Note that these videos are not tied to the textbook and therefore do not use the language, symbols, and conceptual approaches of the book and ALG. The authors therefore recommend assigning these videos after class to expose students to different terminology and notation that they may come across from other sources.

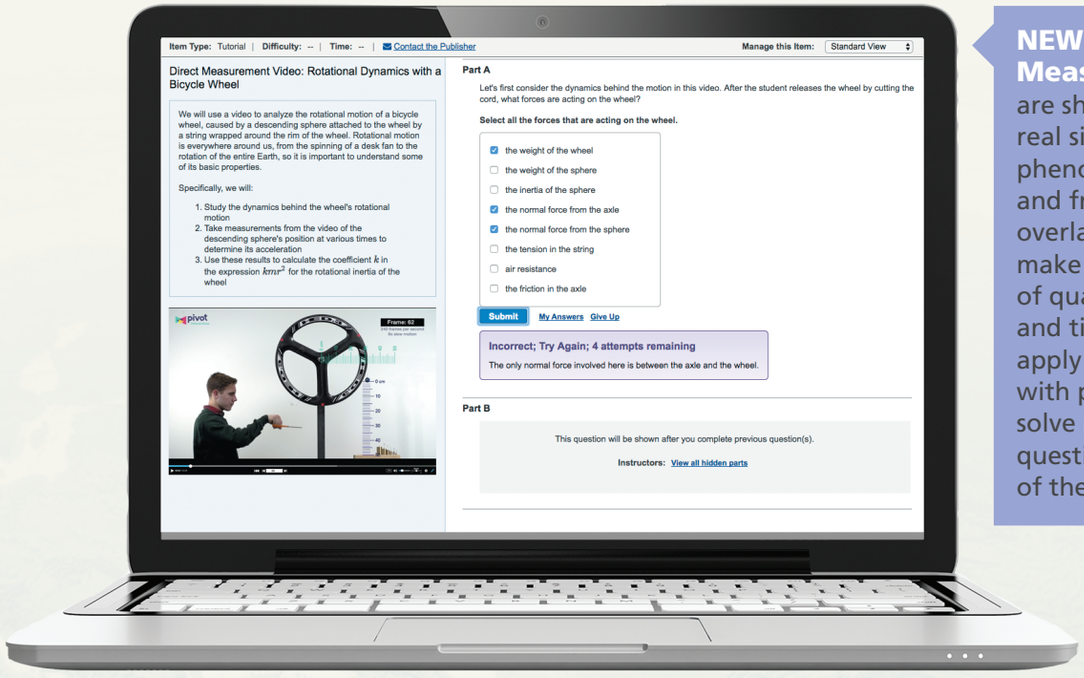

1. Concepts of Motion
Quantitative Video: Acceleration
Item Type: Reading Questions | Difficulty: 2 | Time: 8m | Learning Outcomes | Contact the Publisher
Manage this Item: Standard View
Quantitative Video: Acceleration
Click Play to watch the video below. Answer the ungraded questions in the video and the graded follow-up questions at right.
Part A
A driver parked his car on a steep hill and forgot to set the emergency brake. As a result, the car rolled down the hill and crashed into a parked truck. If the car was moving at 10 mph (4.5 m/s) when it hit the truck 7.0 seconds after it began to move, what was the car's average acceleration while it rolled down the hill? Define the positive x direction to be down the hill.
1.4 m/s² i
-1.4 m/s² i
-0.6 m/s² i
1.6 m/s² i
0.6 m/s² i
-1.6 m/s² i
Submit
My Answers
Give Up
Incorrect; Try Again
Be careful about the units used in this calculation.



Dynamic Study Modules (DSMs) help students study effectively on their own by continuously assessing their activity and performance in real time and adapting to their level of understanding. The content focuses on definitions, units, and the key relationships for topics across all of mechanics and electricity and magnetism.

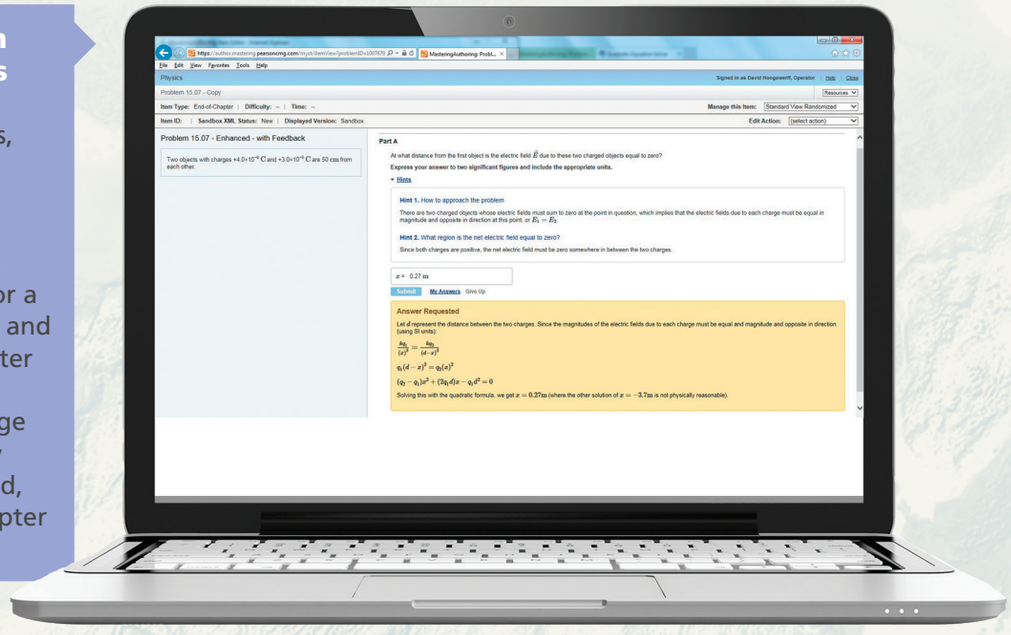
www.MasteringPhysics.com

Show connections between physics and the real world as students learn to apply physics concepts via enhanced media

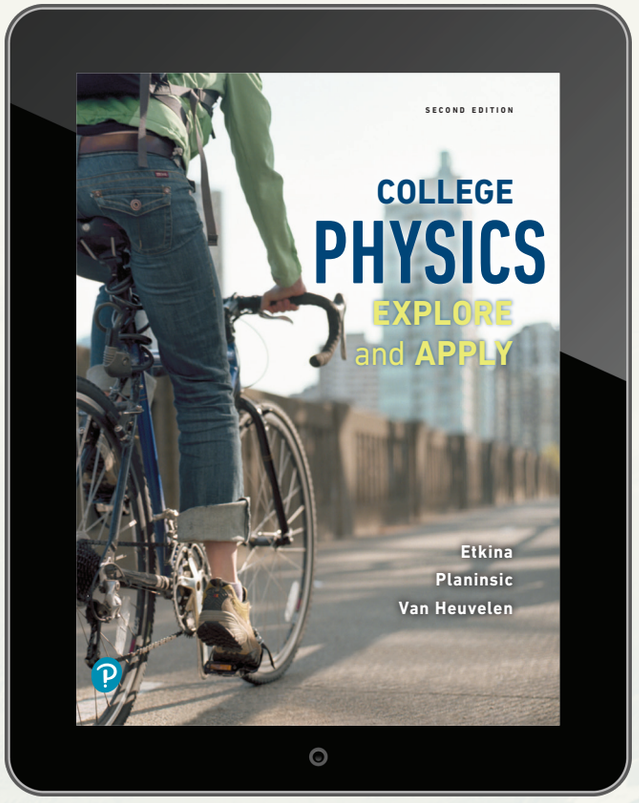

Item Type: Tutorial | Difficulty: -- | Time: -- | Contact the Publisher
Manage this Item: Standard View
Direct Measurement Video: Rotational Dynamics with a Bicycle Wheel
We will use a video to analyze the rotational motion of a bicycle wheel, caused by a descending sphere attached to the wheel by a string wrapped around the rim of the wheel. Rotational motion is everywhere around us, from the spinning of a desk fan to the rotation of the entire Earth, so it is important to understand some of its basic properties.
Specifically, we will:
1. Study the dynamics behind the wheel's rotational motion
2. Take measurements from the video of the descending sphere's position at various times to determine its acceleration
3. Use these results to calculate the coefficient k in the expression $krmr^2$ for the rotational inertia of the wheel
pivot
Frame: 62
Part A
Let's first consider the dynamics behind the motion in this video. After the student releases the wheel by cutting the cord, what forces are acting on the wheel?
Select all the forces that are acting on the wheel.
the weight of the wheel
the weight of the sphere
the inertia of the sphere
the normal force from the axle
the normal force from the sphere
the tension in the string
air resistance
the friction in the axle
Submit
My Answers
Give Up
Incorrect; Try Again; 4 attempts remaining
The only normal force involved here is between the axle and the wheel.
Part B
This question will be shown after you complete previous question(s).
Instructors: View all hidden parts

NEW! Direct Measurement Videos are short videos that show real situations of physical phenomena. Grids, rulers, and frame counters appear as overlays, helping students to make precise measurements of quantities such as position and time. Students then apply these quantities along with physics concepts to solve problems and answer questions about the motion of the objects in the video.

NEW! End-of-chapter problem types and 15% new questions and problems include multiple choice with multiple correct answers, find-a-pattern in data presented in a video or a table, ranking tasks, evaluate statements/claims/explanations/measuring procedures, evaluate solutions, design a device or a procedure that meets given criteria, and linearization problems. End-of-chapter problems have undergone careful analysis using Mastering Physics usage data to provide fine-tuned difficulty ratings and to produce a more varied, useful, and robust set of end-of-chapter problems.

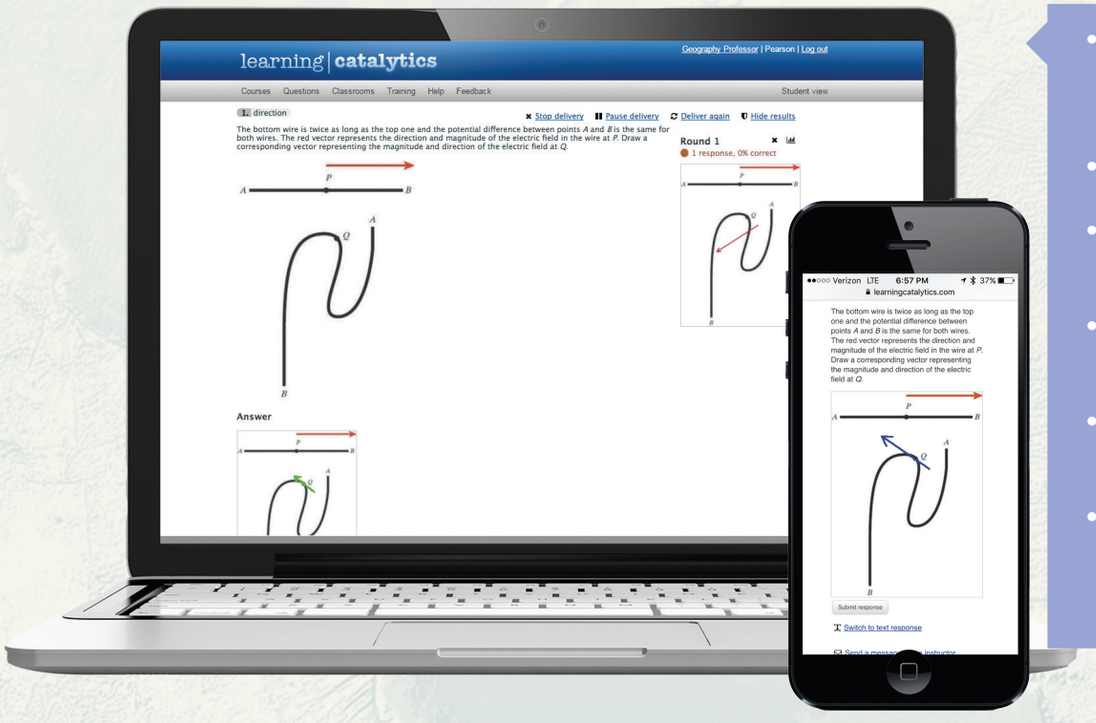

Physics
Problem 15.07 - Copy
Item Type: End-of-Chapter | Difficulty: -- | Time: --
Manage this Item: Standard View Randomized
Edit Action: (select action)
Problem 15.07 - Enhanced - with Feedback
Two objects with charges +4.0×10⁻⁶ C and +3.0×10⁻⁶ C are 50 cm from each other.
Part A
At what distance from the first object is the electric field $\vec{E}$ due to these two charged objects equal to zero?
Express your answer to two significant figures and include the appropriate units.
Hints
Hint 1. How to approach the problem
There are two charged objects whose electric fields must sum to zero at the point in question, which implies that the electric fields due to each charge must be equal in magnitude and opposite in direction at this point, or $\vec{E}_1 = -\vec{E}_2$.
Hint 2. What region is the net electric field equal to zero?
Since both charges are positive, the net electric field must be zero somewhere in between the two charges.
x = 0.27 m
Submit
My Answers
Give Up
Answer Requested
Let d represent the distance between the two charges. Since the magnitudes of the electric fields due to each charge must be equal and magnitude and opposite in direction (using SI units)
$\frac{kq_1}{(x)^2} = \frac{kq_2}{(d-x)^2}$
$q_1(d-x)^2 = q_2(x)^2$
$(q_2 - q_1)x^2 + (2q_1d)x - q_1d^2 = 0$
Solving this with the quadratic formula, we get $x = 0.27$m (where the other solution of $x = -3.7$m is not physically reasonable).

Give students fingertip access to interactive tools



NEW! Pearson eText, optimized for mobile, seamlessly integrates videos such as the Observational Experiment Tables and other rich media with the text and gives students access to their textbook anytime, anywhere. Pearson eText is available with Mastering Physics when packaged with new books or as an upgrade students can purchase online.

Learning Catalytics™ helps generate class discussion, customize lectures, and promote peer-to-peer learning with real-time analytics. Learning Catalytics acts as a student response tool that uses students' smartphones, tablets, or laptops to engage them in more interactive tasks and thinking.


learning | catalytics
Geography Professor | Pearson | Log out
Courses Questions Classrooms Training Help Feedback
Student view
1/ direction
Stop delivery
Pause delivery
Deliver again
Hide results
The bottom wire is twice as long as the top one and the potential difference between points A and B is the same for both wires. The red vector represents the direction and magnitude of the electric field in the wire at P. Draw a corresponding vector representing the magnitude and direction of the electric field at Q.
Round 1
1 response, 0% correct
Answer
Verizon LTE 6:57 PM 37%
learningcatalytics.com
Submit response
Switch to text response

- **NEW!** Upload a full PowerPoint® deck for easy creation of slide questions.
- **NEW!** Team names are no longer case sensitive.
- Help your students develop critical thinking skills.
- Monitor responses to find out where your students are struggling.
- Rely on real-time data to adjust your teaching strategy.
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GORAZD PLANINSIC is a Professor of Physics at the University of Ljubljana, Slovenia. He has a PhD in physics from the University of Ljubljana. Since 2000 he has led the Physics Education program, which prepares almost all high school physics teachers in the country of Slovenia. He started his career in MRI physics and later switched to physics education research. During the last 10 years, his work has mostly focused on the research of new experiments and how to use them more productively in teaching and learning physics. He is co-founder of the Slovenian hands-on science center House of Experiments. Professor Planinsic is co-author of more than 80 peer-refereed research articles and more than 20 popular science articles, and is the author of a university textbook for future physics teachers. In 2013 he received the Science Communicator of the Year award from the Slovenian Science Foundation.

ALAN VAN HEUVELEN holds a PhD in physics from the University of Colorado. He has been a pioneer in physics education research for several decades. He taught physics for 28 years at New Mexico State University, where he developed active learning materials including the *Active Learning Problem Sheets* (the *ALPS Kits*) and the *ActivPhysics* multimedia product. Materials such as these have improved student achievement on standardized qualitative and problem-solving tests. In 1993 he joined Ohio State University to help develop a physics education research group. He moved to Rutgers University in 2000 and retired in 2008. For his contributions to national physics education reform, he won the 1999 AAPT Millikan Medal and was selected a fellow of the American Physical Society. Over the span of his career he has led over 100 workshops on physics education reform. He worked with Professor Etkina in the development of the *Investigative Science Learning Environment* (ISLE) and co-authored the first edition of *College Physics* and the *Active Learning Guide*.

Preface

You are holding the second edition of *College Physics: Explore and Apply*. The very title reflects the unifying philosophy of the textbook and supporting materials that consistently permeates every chapter: students are guided to explore natural phenomena by observing simple experiments, finding patterns in their observations, explaining the patterns, testing their explanations in new experiments and, finally, applying the conclusions to solve practical problems. This pedagogical approach is called *ISLE* – the Investigative Science Learning Environment –and it is totally consistent with the goals of the Next Generation Science Standards and the revised AP curriculum.

In essence, the ISLE approach to learning physics places the student in the driver's seat of exploring the world, equipping them with the tools they need for this journey. The tools are the science practices that are deliberately and consistently developed in **every chapter** of the textbook and in the systematically organized activities in the *Active Learning Guide* (ALG). The ISLE philosophy allows students to experience the same logical approach to the invention, testing, and application of every single concept (qualitative or quantitative) throughout both the AP I and AP II courses, thus making them expert thinkers and successful solvers of non-traditional problems. For ISLE students, physics concepts are not truths handed down to them by authority, but models, explanations, and relations that they have constructed themselves under the guidance of you, their teacher, and with the help of the materials that we have created.

Below you will find three tables that demonstrate

(1) how the book's AP-style non-traditional problems help students prepare for AP exams and future NGSS-based assessments to come.

(2) how each chapter helps develop *all* science practices (not only those paired with specific enduring understanding), and

(3) how the material in the textbook and the ALG addresses enduring understanding for both courses.

Note that the learning system also includes the *Instructor's Guide* (IG). In each chapter of the IG we provide a table showing the numbers of the problems and questions of specific new types. We hope that this short introduction and organizing tables will help you take full advantage of the materials that we have developed. If you have any questions, please do not hesitate to contact Eugenia Etkina directly at Eugenia.etkina@gse.rutgers.edu.

TABLE 1: Novel problems and how they help students develop specific science practices

We have bolded the main practice that is addressed. A list of the novel problems by chapter is given in the *Instructor's Guide*.

Type of problem	Description	Practices developed
Ranking tasks (RAT)	Students have to rank the values of a certain physical quantity for different situations, in descending or ascending order.	SP **1**, 6
Choose answer and explanation (CAE)	Students have to choose the correct answer ***and*** the correct matching explanation (cause-effect or mechanistic) in order to get full credit.	SP **6**
Choose measuring procedure (MEP)	Students have to choose (or propose) the correct (or the best) experimental procedure that will allow them to measure/determine a certain quantity.	SP **4**
Evaluate (reasoning, solution. . .) (EVA)	Students have to critically evaluate the reasoning of some (imaginary) people or evaluate the suggested solution to a problem (given either in words, graphs, diagrams, or as an equation). Students have to recognize productive ideas (even when they are embedded in incorrect answers) and differentiate them from unproductive ideas.	SP 1, 2, **3** and **6**
Make judgment (based on data) (MJU)	Students have to make a judgement about one or more hypotheses, based on data or other forms of evidence that are given in the problem, sometimes taking uncertainties into account.	SP 2, 4, **5**, **6**

Type of problem	Description	Practices developed
Linearization (LIN)	First, students have to write an equation that describes the relevant situation. Then they have to rearrange the equation to obtain a linear function (note that the independent and dependent variables in this function can be any function of the data given in the problem). Students then draw the graph and determine the unknown quantities using the best-fit line. These problems help students combine knowledge of physics, the ability to "read and write" with graphs, the ability to manipulate equations, and the ability to recognize linear dependence in non-standard situations.	SP **1, 2, 5**
Multiple possibility and tell all (MPO)	Students have to list as many quantities as they can that can be determined based on data given in the problem, or tell everything they can about the physical attributes of the objects that appear in the text or the relations between them. Normally, students are required to determine the values for only few of the quantities that they identify. These problems allow all students to feel successful.	SP 1, **3** and 7
Jeopardy (JEO)	Students have to convert a representation of a solution into a problem statement. If the solution is given in the form of an equation, they need to understand the meaning of the quantities and their units. Such problems emphasize the value of units.	SP **1, 2** and 3
Design an experiment (or pose a problem) (DEX)	Students have to design an experiment, an experimental procedure, or a device that will allow them to measure/determine certain physical quantities or that would meet specific requirements. Students have to pose a problem that involves certain objects with given characteristics. Often there is an additional requirement that solving the problem should involve the use of a particular physics topic, law, or principle. Students may also need to do an additional literature search.	SP **3** and **4**
Problem based on real data (RED)	Students have to solve problems that are based on real data, obtained in real-life situations, often using easily available equipment and/or equipment that is typically used in student labs. The types of problems may be traditional or any of the types presented above. Students need to deal with uncertainties, anomalous data, and assumptions, and to propose meaningful models.	SP 5, **7**

TABLE 2: Science practices and how they are addressed in our materials

Science Practice	How it is addressed in every chapter of the textbook	How it is addressed in the end-of-chapter problems	How it is addressed in every chapter of the ALG
Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.	Analysis of Observational Experiment Tables, Physics Tool Boxes, and the representation-based problem-solving strategy used in *every* worked example, especially Conceptual Exercises that use multiple representations but not mathematics. New types of representations.	Some traditional problems + RAT, LIN and JEO problems But also in EVA and MPO problems	The ALG has several types of activities where the student needs to move between representations without solving for anything – "Represent and reason" activities.
Science Practice 2: The student can use mathematics appropriately.	In every chapter, the relations are classified into operational definitions and cause-effect relationships, and the mathematical meaning of every new equation is explicitly discussed. Worked examples show *all* mathematical steps without skipping anything. Every answer is evaluated.	Several traditional problems + LIN and JEO problems But also in EVA and MJU problems	Students develop mathematical relations on their own in "Reason" and "Derive" activities, they also use mathematics to solve practical problems in "Design an application experiment" activities, "Evaluate the solution" activities help students identify mistakes in given solutions.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations.	Observational and Testing Experiments show students how to pose and answer scientific questions, how to create and test hypotheses, how to differentiate between hypotheses (explanations) and predictions, and learn how to reject hypotheses.	EVA, MPO and DEX (or pose a problem) problems But also in JEO problems	"Design an experiment" or "Pose your own problem" activities explicitly engage students in this practice.
Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question.	Observational and Testing experiment tables show students how to plan and implement data collection.	MEP and DEX (or pose a problem) problems But also in MJU problems	In every "Test your idea" activity, the students need to plan an experiment and data collection and make a prediction about the outcome of the experiment based on the idea being tested. "Design an experiment" activities also require students to plan the experiment and data collection.

Science Practice	How it is addressed in every chapter of the textbook	How it is addressed in the end-of-chapter problems	How it is addressed in every chapter of the ALG
Science Practice 5: The student can perform data analysis and evaluation of evidence.	Observational and Testing experiment tables show students how to carry out data analysis. Many worked examples discuss data analysis.	MJU, LIN problems But also in RED problems	"Observe and find a pattern" activities either require students to perform an experiment and collect data and analyze them or provide the student with a set of data (either in a tabular or graphical form) for the students to analyze and evaluate.
Science Practice 6: The student can work with scientific explanations and theories.	The textbook explicitly shows where new scientific explanations come from (evidence, experiments, analogical reasoning, etc.), how they are tested experimentally, and how they are applied.	Some traditional problems + CAE, EVA, MJU problems But also in RAT	"Explain" and "Test your idea" activities engage students in making and testing explanations. "Reading exercises" at the end of each section encourage the students to read the section and answer Review Questions that connect their activities to what is written in the section. "Evaluate the solution" activities engage students in the assessment of somebody else's explanations.
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across the domains.	The ISLE logical flow and the same experiential approach are present in every chapter. Students see consistency in the explorations of different topics. The concept of a system connects across macro and micro worlds. The textbook uses the same representation such as force diagrams or energy bar charts not only in mechanics but also in fluids, electrostatics, magnetism, quantum optics, atomic and nuclear physics. Each section has Review Questions teaching the student to read the book critically.	RED problems But also in MPO problems	"Represent and reason" activities, engage students in representing phenomena in multiple ways with the same most fundamental representations in every chapter. "Design an experiment" activities have the same guiding questions independent of the content which allow the students see the consistency of science practices across domains. "Reading exercises" teach them to critically read the text. Finally, an appendix of specifically designed "Challenge" activities that do not belong to any one chapter's content, challenge students to observe a new phenomenon, decide how to explain it, and test their explanations.

Correlation to the AP® Physics 1 and AP® Physics 2 Curriculum Framework

This table correlates the College Board's Advanced Placement® Physics Curriculum Framework (effective Fall 2017) to the corresponding chapters and sections in *College Physics: Explore and Apply 2nd Edition*, AP Edition. For the most current correlation for this textbook, visit PearsonSchool.com/AdvancedCorrelations.

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.A:	Science Practices	Chapter/Section	AP Physics
The internal structure of a system determines many properties of the system.			
1.A.1. A system is an object or a collection of objects. Objects are treated as having no internal structure.		3.1, 6.1, 8.1, 30.3	Phys. 1
1.A.2. Fundamental particles have no internal structure.	SP 1.1; 7.2	30.3	Phys. 2
1.A.3. Nuclei have internal structures that determine their properties.		29.1, 29.2, 29.6	Phys. 2
1.A.4. Atoms have internal structures that determine their properties.	SP 1.1; 7.1	27.2, 27.6, 28.1–28.3, 28.7	Phys. 2
1.A.5. Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an *object*.	SP 1.1; 1.4; 7.1	12.1, 19.10	Phys. 1; 2
Enduring Understanding 1.B:			
Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.			
1.B.1. Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.	SP 6.4; 7.2	17.3, 19.1, 19.3	Phys. 1; 2
1.B.2. There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.	SP 6.1; 6.2; 6.4; 7.2	17.1, 17.2	Phys. 1; 2
1.B.3. The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.	SP 1.5; 6.1; 7.2	17.2, 17.3	Phys. 1; 2
Enduring Understanding 1.C:			
Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.			
1.C.1. Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.	SP 4.2	3.5	Phys. 1
1.C.2. Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.		3.6, 4.5, 5.5, 18.1	Phys. 1
1.C.3. Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	SP 4.2	3.6, 5.5, 6.1	Phys. 1
1.C.4. In certain processes, mass can be converted to energy and energy can be converted to mass according to $E = mc^2$, the equation derived from the theory of special relativity.	SP 6.3	26.9, 29.3–29.5, 30.1	Phys. 2
Enduring Understanding 1.D:			
Classical mechanics cannot describe all properties of objects.			
1.D.1. Objects classically thought of as particles can exhibit properties of waves.	SP 6.3	28.6	Phys. 2
1.D.2. Certain phenomena classically thought of as waves can exhibit properties of particles.		27.1, 27.3, 27.4	Phys. 2
1.D.3. Properties of space and time cannot always be treated as absolute.	SP 6.3; 7.1	26.3–26.6, 26.9, 26.11, 26.12	Phys. 2
Enduring Understanding 1.E:			
Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.			
1.E.1. Matter has a property called density.	SP 4.1; 4.2; 6.4	12.2, 13.1	Phys. 2
1.E.2. Matter has a property called resistivity.	SP 4.1	19.10	Phys. 1; 2
1.E.3. Matter has a property called thermal conductivity.	SP 4.1; 4.2; 5.1	15.7	Phys. 2
1.E.4. Matter has a property called electric permittivity.		18.6, 25.2	Phys. 2
1.E.5. Matter has a property called magnetic permeability.		20.5, 25.2	Phys. 2
1.E.6. Matter has a property called magnetic dipole moment.		20.7	Phys. 2

Big Idea 2: Fields existing in space can be used to explain interactions.			
Enduring Understanding 2.A:	**Science Practices**	**Chapter/Section**	**AP Physics**
A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.			
2.A.1. A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.		18.1, 18.2, 20.2	Phys. 1; 2
2.A.2. A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential.		18.3	Phys. 2
Enduring Understanding 2.B:			
A gravitational field is caused by an object with mass.			
2.B.1. A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.	SP 2.2; 7.2	3.6, 13.3, 18.1	Phys. 1
2.B.2. The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.	SP 2.2	9.6, 18.1	Phys. 1
Enduring Understanding 2.C:			
An electric field is caused by an object with electric charge.			
2.C.1. The magnitude of the electric force F exerted on an object with electric charge q by an electric field $\vec{E}$ is $\vec{F} = q\vec{E}$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distribution, and uniformly charged parallel plates.	SP 2.2; 6.4; 7.2	18.1	Phys. 2
2.C.2. The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.	SP 2.2; 6.4	18.1	Phys. 2
2.C.3. The electric field outside a spherically symmetric charged object is radial and its magnitude varies as the inverse square of the radial distance from the center of that object. Electric field lines are not in the curriculum. Students will be expected to rely only on the rough intuitive sense underlying field lines, wherein the field is viewed as analogous to something emanating uniformly from a source.	SP 6.2	18.1, 18.2, 18.5	Phys. 2
2.C.4. The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.	SP 1.4; 2.2; 6.4; 7.2	18.1, 18.2	Phys. 2
2.C.5. Between two oppositely charged parallel plates with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction.	SP 1.1; 2.2; 7.1	18.7	Phys. 2
Enduring Understanding 2.D:			
A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles.			
2.D.1. The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. Treatment is quantitative for angles of 0°, 90°, or 180° and qualitative for other angles.	SP 2.2	20.3, 20.4, 20.6	Phys. 2
2.D.2. The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire.	SP 1.1	20.2, 20.3, 20.5	Phys. 2
2.D.3. A magnetic dipole placed in a magnetic field, such as the ones created by a magnet or the Earth, will tend to align with the magnetic field vector.	SP 1.2	20.2, 20.5	Phys. 2
2.D.4. Ferromagnetic materials contain magnetic domains that are themselves magnets.	SP 1.4	20.1, 20.2	Phys. 2
Enduring Understanding 2.E:			
Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.			

Enduring Understanding 2.E:			
2.E.1. Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational and electrical potential and potential differences.]	SP 1.4; 6.4; 7.2	18.3	Phys. 2
2.E.2. Isolines in a region where an electric field exists represent lines of equal electric potential, referred to as equipotential lines.	SP 1.4; 6.4; 7.2	18.3	Phys. 2
2.E.3. The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position (displacement) in the relevant direction.		18.4, 18.7	Phys. 2
Big Idea 3: The interactions of an object with other objects can be described by forces.			
Enduring Understanding 3.A:	**Science Practices**	**Chapter/Section**	**AP Physics**
All forces share certain common characteristics when considered by observers in inertial reference frames.			
3.A.1. An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.	SP 1.5; 2.1; 2.2; 4.2; 5.1	2.1–2.9, 3.3, 3.4, 3.9, 4.4, 4.5, 5.2, 5.4, 8.3, 10.2, 26.1	Phys. 1
3.A.2. Forces are described by vectors.	SP 1.1	3.1, 3.2, 3.5, 3.7, 4.1, 4.2	Phys. 1; 2
3.A.3. A force exerted on an object is always due to the interaction of that object with another object.	SP 1.4; 6.1; 6.4; 7.2	3.1, 3.3–3.5, 3.8, 3.9, 4.6, 5.1	Phys. 1; 2
3.A.4. If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.	SP 1.4; 6.2; 6.4; 7.2	3.8, 4.3, 4.6, 6.3	Phys. 1; 2
Enduring Understanding 3.B:			
Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$.			
3.B.1. If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.	SP 1.5; 2.2; 4.2; 5.1; 6.4; 7.2	3.5, 3.7, 4.2, 4.4–4.6, 5.3–5.5, 7.3, 8.3, 8.5, 9.3, 10.3, 13.3	Phys. 1; 2 19.6
3.B.2. Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.	SP 1.1; 1.4; 2.2	3.1, 3.2, 3.5, 3.7–3.9, 4.3, 4.4, 4.6, 5.4, 8.5, 10.5	Phys. 1; 2
3.B.3. Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum, mass-spring oscillator.	SP 2.2; 4.2; 5.1; 6.2; 6.4; 7.2	10.1–10.3, 10.8	Phys. 1
Enduring Understanding 3.C:			
At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.			
3.C.1. Gravitational force describes the interaction of one object that has mass with another object that has mass.	SP 2.2	3.6, 3.7, 5.5, 8.1	Phys. 1
3.C.2. Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.	SP 2.2; 6.4; 7.2	17.1–17.7, 28.1, 29.3	Phys. 1; 2
3.C.3. A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet.	SP 1.4; 4.2; 5.1	20.1, 20.3, 20.4, 20.6, 21.1	Phys. 2
3.C.4. Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).	SP 6.1; 6.2	3.1, 3.7, 4.3, 4.6, 7.4, 10.1, 10.3, 10.7, 13.5, 13.7	Phys. 1; 2
Enduring Understanding 3.D:			
A force exerted on an object can change the momentum of the object.			
3.D.1. The change in momentum of an object is a vector in the direction of the net force exerted on the object.	SP 4.1	6.3, 6.4, 6.7	Phys. 1
3.D.2. The change in momentum of an object occurs over a time interval.	SP 2.1; 4.2; 5.1; 6.4	6.3, 6.4, 12.3	Phys. 1
Enduring Understanding 3.E:			
A force exerted on an object can change the kinetic energy of the object.			

3.E.1. The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted.	SP 1.4; 2.2; 6.4; 7.2	7.1, 7.3, 7.5, 20.4, 28.1	Phys. 1
Enduring Understanding 3.F:			
A force exerted on an object can cause a torque on that object.			
3.F.1. Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.	SP 1.4; 2.2; 2.3; 4.1; 4.2; 5.1	8.2, 8.5	Phys. 1
3.F.2. The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.	SP 4.1; 4.2; 5.1; 6.4	8.3, 8.5, 8.6, 9.1–9.3	Phys. 1
3.F.3. A torque exerted on an object can change the angular momentum of an object.	SP 2.1; 4.1; 4.2; 5.1; 5.3; 6.4; 7.2	9.4	Phys. 1
Enduring Understanding 3.G:			
Certain types of forces are considered fundamental.			
3.G.1. Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.	SP 7.1	30.2	Phys. 1, 2
3.G.2. Electromagnetic forces are exerted at all scales and can dominate at the human scale.	SP 7.1	30.2	Phys. 2
3.G.3. The strong force is exerted at nuclear scales and dominates the interactions of nucleons.	SP 7.2	30.2	Phys. 2
Big Idea 4: Interactions between systems can result in changes in those systems.			
Enduring Understanding 4.A:	**Science Practices**	**Chapter/Section**	**AP Physics**
The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.			
4.A.1. The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.	SP 1.2; 1.4; 2.3; 6.4	4.4, 4.5, 5.2, 5.4, 6.3, 8.3, 10.2	Phys. 1
4.A.2. The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.	SP 1.4; 2.2; 5.3; 6.4	4.2, 4.4, 4.5, 5.1, 8.3, 8.5, 8.6	Phys. 1
4.A.3. Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.	SP 1.4; 2.2	6.3, 6.6	Phys. 1
Enduring Understanding 4.B:			
Interactions with other objects or systems can change the total linear momentum of a system.			
4.B.1. The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.	SP 1.4; 2.2; 5.1	8.3	Phys. 1
4.B.2. The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.	SP 2.2; 5.1	6.2, 6.3, 6.5, 6.6	Phys. 1
Enduring Understanding 4.C:			
Interactions with other objects or systems can change the total energy of a system.			
4.C.1. The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy.	SP 1.4; 2.1; 2.2; 6.4	7.2–7.4, 7.6, 7.9, 9.5, 10.4, 10.5, 12.4, 14.4, 15.1, 17.5, 21.5	Phys. 1
4.C.2. Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work.	SP 1.4; 2.2; 6.4; 7.2	7.2, 7.6, 14.4, 15.1	Phys. 1
4.C.3. Energy is transferred spontaneously from a higher temperature system to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat.	SP 6.4	15.7, 16.1	Phys. 2
4.C.4. Mass can be converted into energy and energy can be converted into mass.	SP 2.2; 2.3; 7.2	26.9, 29.3, 29.4, 30.1	Phys. 2
Enduring Understanding 4.D:			
A net torque exerted on a system by other objects or systems will change the angular momentum of the system.			
4.D.1. Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis.	SP 1.2; 1.4; 3.2; 4.1; 4.2; 5.1; 5.3	8.2, 8.3, 8.6, 9.1, 9.2, 9.4	Phys. 1
4.D.2. The angular momentum of a system may change due to interactions with other objects or systems.	SP 1.2; 1.4; 4.2	9.4, 9.6	Phys. 1

Enduring Understanding 4.D:			
4.D.3. The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.	SP 2.2; 4.1; 4.2	9.5, 9.6	Phys. 1
Enduring Understanding 4.E:			
The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.			
4.E.1. The magnetic properties of some materials can be affected by magnetic fields at the system. Students should focus on the underlying concepts and not the use of the vocabulary.	SP 1.1; 1.4; 2.2	20.7	Phys. 2
4.E.2. Changing magnetic flux induces an electric field that can establish an induced emf in a system.	SP 6.4	21.1, 21.3–21.5, 21.7, 25.2	Phys. 2
4.E.3. The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.	SP 1.1; 1.4; 3.2; 4.1; 4.2; 5.1; 5.3; 6.4; 7.2	17.1, 17.7, 18.5	Phys. 2
4.E.4. The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry.	SP 2.2; 4.1; 4.2; 5.1; 6.4	18.7, 19.4, 19.10	Phys. 2
4.E.5. The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.	SP 2.2; 4.2; 5.1; 6.1; 6.4	19.4, 19.5, 19.8	Phys. 2
Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.			
Enduring Understanding 5.A:	**Science Practices**	**Chapter/Section**	**AP Physics**
Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.			
5.A.1. A system is an object or a collection of objects. The objects are treated as having no internal structure.		3.1, 6.1	Phys. 1
5.A.2. For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.	SP 6.4; 7.2	6.4, 7.2, 9.4, 14.4, 15.3, 19.7, 29.4	Phys. 1
5.A.3. An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.		3.1, 6.2, 15.2, 17.1, 20.1, 30.2	Phys. 1
5.A.4. The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.	Phys. 1	3.1, 6.1, 6.6, 6.7, 7.1, 7.5, 15.2	
Enduring Understanding 5.B:			
The energy of a system is conserved.			
5.B.1. Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.	SP 1.4; 1.5; 2.2	7.3, 9.5	Phys. 1
5.B.2. A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums. Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration.]	SP 1.4; 2.1	10.4, 10.5, 17.5, 17.6	Phys. 1; 2
5.B.3. A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.	SP 1.4; 2.2; 6.4; 7.2	7.3, 7.4, 7.9, 10.4, 10.5, 17.5, 19.2, 27.2, 28.2	Phys. 1
5.B.4. The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.	SP 1.4; 2.1; 2.2; 6.4; 7.2	10.4, 10.5, 12.8, 15.1, 27.2, 28.2	Phys. 1; 2
5.B.5. Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.]	SP 1.4; 2.2; 4.2; 5.1; 6.4; 7.2	7.2–7.6, 7.8, 7.9, 10.8, 14.4, 17.5, 18.4	Phys. 1; 2
5.B.6. Energy can be transferred by thermal processes involving differences in temperature; the amount of energy transferred in this process of transfer is called heat.	SP 1.2	15.2, 15.7, 16.4, 27.1	Phys. 2
5.B.7. The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams — isovolumetric process, isothermal process, isobaric process, adiabatic process. No calculations of heat or internal energy from temperature change; and in this course, examples of these relationships are qualitative and/or semi-quantitative.		15.3, 15.4, 15.7, 16.1, 16.4	Phys. 2
5.B.8. Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.	SP 1.2; 7.2	28.2, 28.3	Phys. 2

5.B.9. Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.	SP 1.1; 1.4; 1.5; 2.1; 2.2; 4.1; 4.2; 5.1; 5.3; 6.4; 7.2	19.2, 19.5–19.7, 21.4, 21.7	Phys. 1; 2
5.B.10. Bernoulli's equation describes the conservation of energy in fluid flow.	SP 2.2; 6.2	14.1, 14.4, 14.5	Phys. 2
5.B.11. Beyond the classical approximation, mass is actually part of the internal energy of an object or system with $E = mc^2$.		29.3–29.5, 30.1	Phys. 2
Enduring Understanding 5.C:			
The electric charge of a system is conserved.			
5.C.1. Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed. Examples should include equations representing nuclear decay.	SP 6.4; 7.2	29.4, 29.6	Phys. 2
5.C.2. The exchange of electric charges among a set of objects in a system conserves electric charge.	SP 4.1; 4.2; 5.1; 6.4	17.2, 17.3, 18.5	Phys. 2
5.C.3. Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only. Physics 2: includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.]	SP 1.4; 2.2; 4.1; 4.2; 5.1; 6.4; 7.2	19.7	Phys. 1; 2
Enduring Understanding 5.D:			
The linear momentum of a system is conserved.			
5.D.1. In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.	SP 2.1; 2.2; 3.2; 4.2; 5.1; 5.3; 6.4; 7.2	6.3–6.7, 7.7	Phys. 1; 2
5.D.2. In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.	SP 2.1; 2.2; 4.1; 4.2; 4.4; 5.1; 5.3; 6.4; 7.2	6.3, 6.4, 6.6, 6.7, 7.7	Phys. 1; 2
5.D.3. The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]	SP 6.4	8.1, 8.4	Phys. 1; 2
Enduring Understanding 5.E:			
The angular momentum of a system is conserved.			
5.E.1. If the net external torque exerted on the system is zero, the angular momentum of the system does not change.	SP 2.1; 2.2; 6.4; 7.2	9.4	Phys. 1
5.E.2. The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples should include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem.	SP 2.2	9.3, 9.4	Phys. 1
Enduring Understanding 5.F:			
Classically, the mass of a system is conserved.			
5.F.1. The continuity equation describes conservation of mass flow rate in fluids. Examples should include volume rate of flow, mass flow rate.	SP 2.1; 2.2; 7.2	14.2	Phys. 2
Enduring Understanding 5.G:			
Nucleon number is conserved.			
5.G.1. The possible nuclear reactions are constrained by the law of conservation of nucleon number.	SP 6.4	29.4, 29.6	Phys. 2
Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.			
Enduring Understanding 6.A:	**Science Practices**	**Chapter/Section**	**AP Physics**
A wave is a traveling disturbance that transfers energy and momentum.			
6.A.1. Waves can propagate via different oscillation modes such as transverse and longitudinal.	SP 1.2; 5.1; 6.2	11.1, 25.1, 25.6	Phys. 1; 2

Enduring Understanding 6.A:			
6.A.2. For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.	SP 6.4; 7.2	11.1, 26.1	Phys. 1; 2
6.A.3. The amplitude is the maximum displacement of a wave from its equilibrium value.	SP 1.4	11.2	Phys. 1
6.A.4. Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves.	SP 6.4	11.4	Phys. 1
Enduring Understanding 6.B:			
A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.			
6.B.1. For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time.	SP 1.4; 2.2	11.2	Phys. 1
6.B.2. For a periodic wave, the wavelength is the repeat distance of the wave.	SP 1.4	11.2	Phys. 1
6.B.3. A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave.	SP 1.5	11.2, 25.5	Phys. 2
6.B.4. For a periodic wave, wavelength is the ratio of speed over frequency.	SP 4.2; 5.1; 7.2	11.2, 11.3, 24.2, 25.4	Phys. 1
6.B.5. The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only.	SP 1.4	11.10, 26.10	Phys. 1
Enduring Understanding 6.C:			
Only waves exhibit interference and diffraction.			
6.C.1. When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition.	SP 1.4; 6.4; 7.2	11.6, 11.7, 24.4	Phys. 2
6.C.2. When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.	SP 1.4; 6.4; 7.2	24.5, 24.6	Phys. 2
6.C.3. When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.	SP 1.4; 6.4	24.1, 24.3	Phys. 2
6.C.4. When waves pass by an edge, they can diffract into the "shadow region" behind the edge. Examples should include hearing around corners, but not seeing around them, and water waves bending around obstacles.	SP 6.4; 7.2	24.5	Phys. 2
Enduring Understanding 6.D:			
Interference and superposition lead to standing waves and beats.			
6.D.1. Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition.	SP 1.1; 1.4; 4.2; 5.1	11.4, 11.7	Phys. 1
6.D.2. Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave.	SP 5.1	11.6, 11.7	Phys. 1
6.D.3. Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes.	SP 1.2; 2.1; 3.2; 4.1; 4.2; 5.1; 5.2; 5.3; 6.4	11.8, 11.9	Phys. 1
6.D.4. The possible wavelengths of a standing wave are determined by the size of the region to which it is confined.	SP 1.5; 2.2; 6.1	11.8, 11.9	Phys. 1
6.D.5. Beats arise from the addition of waves of slightly different frequency.	SP 1.2	11.7	Phys. 1
Enduring Understanding 6.E:			
The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.			
6.E.1. When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. (Qualitative understanding only.)	SP 6.4; 7.2	11.5, 22.3, 25.6	Phys. 2
6.E.2. When light hits a smooth reflecting surface at an angle, it reflects at the same angle on the other side of the line perpendicular to the surface (specular reflection); and this law of reflection accounts for the size and location of images seen in plane mirrors.	SP 6.4; 7.2	22.2, 22.4, 23.1–23.3	Phys. 2
6.E.3. When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.	SP 1.1; 1.4; 4.1; 5.1; 5.2; 5.3; 6.4; 7.2	22.3, 22.4, 23.4, 23.5, 24.2	Phys. 2

6.E.4. The reflection of light from surfaces can be used to form images.	SP 1.4; 2.2; 3.2; 4.1; 5.1; 5.2; 5.3	23.2, 23.3	Phys. 2
6.E.5. The refraction of light as it travels from one transparent medium to another can be used to form images.	SP 1.4; 2.2; 3.2; 4.1; 5.1; 5.2; 5.3	23.4, 23.5, 23.7–23.9	Phys. 2
Enduring Understanding 6.F:			
Electromagnetic radiation can be modeled as waves or as fundamental particles.			
6.F.1. Types of electromagnetic radiation are characterized by their wavelengths, and certain ranges of wavelength have been given specific names. These include (in order of increasing wavelength spanning a range from picometers to kilometers) gamma rays, x-rays, ultraviolet, visible light, infrared, microwaves, and radio waves.	SP 6.4; 7.2	25.3, 25.4, 27.5	Phys. 2
6.F.2. Electromagnetic waves can transmit energy through a medium and through a vacuum.	SP 1.1	25.5, 26.1	Phys. 2
6.F.3. Photons are individual energy packets of electromagnetic waves, with $E_{\text{photon}} = hf$, where h is Planck's constant and f is the frequency of the associated light wave.	SP 6.4	27.1–27.4	Phys. 2
6.F.4. The nature of light requires that different models of light are most appropriate at different scales.	SP 6.4; 7.1	27.3	Phys. 2
Enduring Understanding 6.G:			
All matter can be modeled as waves or as particles.			
6.G.1. Under certain regimes of energy or distance, matter can be modeled as a classical particle.	SP 6.4; 7.1	28.6	Phys. 2
6.G.2. Under certain regimes of energy or distance, matter can be modeled as a wave. The behavior in these regimes is described by quantum mechanics.	SP 6.1; 6.4	28.6	Phys. 2
Big Idea 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.			
Enduring Understanding 7.A:	**Science Practices**	**Chapter/Section**	**AP Physics**
The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.			
7.A.1. The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.	SP 1.4; 2.2; 6.4; 7.2	12.2, 12.3, 13.2–13.5	Phys. 2
7.A.2. The temperature of a system characterizes the average kinetic energy of its molecules.	SP 7.1	12.4–12.6, 12.8, 15.1, 15.2	Phys. 2
7.A.3. In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV = nkT$.	SP 3.2; 4.2; 5.1; 6.4; 7.2	12.4, 12.5, 12.7	Phys. 2
Enduring Understanding 7.B:			
The tendency of isolated systems to move toward states with higher disorder is described by probability.			
7.B.1. The approach to thermal equilibrium is a probability process.	SP 6.2	12.4, 15.5, 15.6	Phys. 2
7.B.2. The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course.	SP 7.1	16.1–16.4	Phys. 2
Enduring Understanding 7.C:			
At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.			
7.C.1. The probabilistic description of matter is modeled by a wave function, which can be assigned to an object and used to describe its motion and interactions. The absolute value of the wave function is related to the probability of finding a particle in some spatial region. (Qualitative treatment only, using graphical analysis.)	SP 1.4	28.6, 28.8	Phys. 2
7.C.2. The allowed states for an electron in an atom can be calculated from the wave model of an electron.	SP 1.4	28.2, 28.6	Phys. 2
7.C.3. The spontaneous radioactive decay of an individual nucleus is described by probability.	SP 6.4	29.7, 29.8	Phys. 2
7.C.4. Photon emission and absorption processes are described by probability.	SP 1.1; 1.2	28.2–28.4	Phys. 2

New to this edition

There were three main reasons behind the revisions in this second edition. (1) Users provided lots of feedback and we wanted to respond to it. (2) We (the authors) grew and changed, and learned more about how to help students learn, and our team changed—we have a new co-author, who is an expert in educational physics experiments and in the development of physics problems. (3) Finally, we wanted to respond to changes in the world (new physics discoveries, new technology, new skills required in the workplace) and to changes in education (the Next Generation Science Standards, reforms in the AP and MCAT exams). Our first edition was already well aligned with educational reforms, but the second edition strengthens this alignment even further.

We have therefore made the following global changes to the textbook, in addition to myriad smaller changes to individual chapters and elements:

- **An enhanced experiential approach**, with more experiment videos and photos (all created by the authors) and an updated and more focused and effective set of experiment tables, strengthens and improves the core foundation of the first edition. Approximately 150 photos and 40 videos have been added to the textbook, and even more to the ALG.
- **An expanded introductory chapter** (now Chapter 1) gives students a more detailed explanation of "How to use this book" to ensure they get the most out of the chapter features, use them actively, and learn how to think critically.
- **Integration of vector arithmetic in early chapters** allows students to develop vector-related skills in the context of learning physics, rather than its placement in an appendix in the first edition.
- **Earlier placement of waves and oscillations** allows instructors to teach these topics with mechanics if preferred. Coverage with optics is also still possible.
- **Significant new coverage of capacitors, AC circuits, and LEDs** (LEDs now permeate the whole book) expand the real-world and up-to-date applications of electricity.
- **Other new, revised, or expanded topics** include friction, 2-D collisions, energy, bar charts for rotational momentum and nuclear energy, ideal gas processes, thermodynamic engines, semiconductors, velocity selectors, and spacetime diagrams in special relativity.
- **Applications are integrated throughout each chapter,** rather than being grouped in the "Putting it all together" sections of the first edition, in order to optimize student engagement.
- **Problem-solving guidance is strengthened** by the careful revision of many Problem-Solving Strategy boxes and the review of each chapter's set of worked examples. The first edition Reasoning Skill boxes are renamed Physics Tool Boxes to better reflect their role; many have been significantly revised.
- **Streamlined text, layout, and figures** throughout the book enhance the focus on central themes and topics, eliminating extraneous detail. The second edition has over 150 fewer pages than the first edition, and the art program is updated with over 450 pieces of new or significantly revised art.
- **21st-century skills incorporated into many new worked examples and end-of-chapter problems** include data analysis, evaluation, and argumentation. Roughly 15% of all end-of-chapter questions and problems are new.
- **Careful analysis of Mastering Physics usage data** provides fine-tuned difficulty ratings and a more varied, useful, and robust set of end-of-chapter problems.
- **A fresh and modern design** provides a more transparent hierarchy of features and navigation structure, as well as an engaging chapter-opening page and streamlined chapter summary.
- **A significantly revised** Active Learning Guide is better integrated with the textbook, following the section sequence, and emphasizes collaboration, scientific reasoning, and argumentation.

All of the above sounds like a lot of work—and it was! But it was also lots of fun: we took photos of juice bottles sinking in the snow, we chased flying airplanes and running water striders, we drove cars with coffee cups on dashboards. Most exciting was our trip to a garbage plant to study and photograph the operation of an eddy current waste separator. Working on this new edition has enriched our lives, and we hope that using our textbook will enrich the lives of your students!

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Instructor's Guide (Online Only)

Written by Eugenia Etkina, Gorazd Planinsic, David Brookes, and Alan Van Heuvelen, this guide walks you through the innovative approaches they take to teaching physics. Each chapter of the *Instructor's Guide* contains a roadmap for assigning chapter content, *Active Learning Guide* assignments, homework, and videos of the experiments. In addition, the authors call out common pitfalls to mastering physics concepts and describe techniques that will help your students identify and overcome their misconceptions. Tips include how to manage the complex vocabulary of physics, when to use classroom response tools, and how to organize lab, lecture, and small group learning time. Drawing from their extensive experience as teachers and researchers, the authors give you the support you need to make *College Physics* work for you.

Instructor's Solutions Manual (Online Only)

The significantly revised *Instructor's Solutions Manual*, provided as PDFs and editable Word files, gives complete solutions to all end-of chapter questions and problems using the textbook's problem-solving strategy.

TestGen Test Bank (Online Only)

The Test Bank, which has also been significantly revised, contains more than 2000 high-quality problems, with a range of multiple-choice, true/false, short-answer, and regular homework type questions. Test files are provided in TestGen® (an easy-to use, fully networkable program for creating and editing quizzes and exams), as well as PDF and Word format.

Active Learning Guide (Online Only)

The *Active Learning Guide* workbook by Eugenia Etkina, David Brookes, Gorazd Planinsic, and Alan Van Heuvelen consists of carefully crafted cycles of in-class activities that provide an opportunity for students to conduct observational experiments, find patterns, develop explanations, and conduct the testing experiments for those explanations described in the textbook before they read it. These learning cycles are interspersed with "pivotal" activities that serve different purposes: (a) to introduce and familiarize students with new representational techniques, (b) to give students practice with representational techniques, (c) to directly address ideas that we know students struggle with (the goal is to encourage that struggle so that students reach a resolution either through their own discussion or by the instructor giving a "time for telling" lecture at the end of the activity), and (d) to provide scaffolding for students to work through an example or a passage in the textbook. The ALG also contains multiple experiments that can be used in labs. Whether the activities are assigned or not, students can always use this workbook to reinforce the concepts they have read about in the text, to practice applying the concepts to real-world scenarios, or to work with sketches, diagrams, and graphs that help them visualize the physics. The ALG is downloadable to share with your class.

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printed and since then has remained a vivid advocate and supporter of ISLE. We are indebted to Charlie Hibbard, who checked and rechecked every fact and calculation in the text. Brett Kraabel prepared detailed solutions for every end-of-chapter problem for the *Instructor's Solutions Manual*. We also want to thank all of the reviewers, in particular Jeremy Hohertz, who put their time and energy to providing thoughtful, constructive, and supportive feedback. We thank Matt Blackman for adding excellent problems to the Test Bank, Katerina Visnjic for her support of ISLE and the idea to expand energy bar charts to nuclear physics, and Mikhail Kagan for timely feedback. Our special thanks go to Lane Seeley for his thoughtful review of the energy chapter, which led to its deep revision. We thank Diane Jammula and Jay Pravin Kumar, who not only became avid supporters and users of ISLE but also helped create instructor resources for the second edition. We thank Ales Mohoric and Sergej Faletic for their suggestions on problems.

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—Eugenia Etkina, Gorazd Planinsic, and Alan Van Heuvelen

Contents

1 Introducing Physics 1
1.1 What is physics? 2
1.2 Modeling 5
1.3 Physical quantities 6
1.4 Making rough estimates 8
1.5 Vector and scalar quantities 8
1.6 How to use this book to learn physics 9

2 Kinematics: Motion in One Dimension 13
2.1 What is motion? 14
2.2 A conceptual description of motion 15
2.3 Operations with vectors 18
2.4 Quantities for describing motion 21
2.5 Representing motion with data tables and graphs 22
2.6 Constant velocity linear motion 24
2.7 Motion at constant acceleration 30
2.8 Displacement of an object moving at constant acceleration 34
2.9 Skills for analyzing situations involving motion 37
Summary 42 • Questions and Problems 43

3 Newtonian Mechanics 51
3.1 Describing and representing interactions 52
3.2 Adding and measuring forces 55
3.3 Conceptual relationship between force and motion 56
3.4 Inertial reference frames and Newton's first law 60
3.5 Newton's second law 61
3.6 Gravitational force law 66
3.7 Skills for applying Newton's second law for one-dimensional processes 67
3.8 Forces come in pairs: Newton's third law 70
3.9 Seat belts and air bags 75
Summary 77 • Questions and Problems 78

4 Applying Newton's Laws 84
4.1 Vectors in two dimensions and force components 85
4.2 Newton's second law in component form 87
4.3 Friction 89
4.4 Skills for analyzing processes involving forces in two dimensions 96
4.5 Projectile motion 102
4.6 Starting and stopping a car 107
Summary 109 • Questions and Problems 110

5 Circular Motion 118
5.1 Qualitative dynamics of circular motion 119
5.2 Analyzing velocity change for circular motion 121
5.3 Radial acceleration and period 123
5.4 Skills for analyzing processes involving circular motion 127
5.5 The law of universal gravitation 133
Summary 139 • Questions and Problems 140

6 Impulse and Linear Momentum 147
6.1 Mass accounting 148
6.2 Linear momentum 149
6.3 Impulse and momentum 153
6.4 The generalized impulse-momentum principle 156
6.5 Skills for analyzing problems using impulse and momentum 159
6.6 Jet propulsion 163
6.7 Collisions in two dimensions 164
Summary 168 • Questions and Problems 169

7 Work and Energy 176
7.1 Work and energy 177
7.2 Energy is a conserved quantity 181
7.3 Quantifying gravitational potential and kinetic energies 186
7.4 Quantifying elastic potential energy 190
7.5 Friction and energy conversion 192
7.6 Skills for analyzing processes using the work-energy principle 194
7.7 Collisions 199

7.8 Power 202
7.9 Improving our model of gravitational potential energy 204
Summary 208 • Questions and Problems 209

8 Extended Bodies at Rest 217
8.1 Extended and rigid bodies 218
8.2 Torque: a new physical quantity 220
8.3 Conditions of equilibrium 227
8.4 Center of mass 230
8.5 Skills for analyzing situations using equilibrium conditions 233
8.6 Stability of equilibrium 237
Summary 242 • Questions and Problems 243

9 Rotational Motion 251
9.1 Rotational kinematics 252
9.2 Physical quantities affecting rotational acceleration 257
9.3 Newton's second law for rotational motion 260
9.4 Rotational momentum 266
9.5 Rotational kinetic energy 271
9.6 Tides and Earth's day 274
Summary 276 • Questions and Problems 277

10 Vibrational Motion 284
10.1 Observations of vibrational motion 285
10.2 Kinematics of vibrational motion 288
10.3 Dynamics of simple harmonic motion 292
10.4 Energy of vibrational systems 295
10.5 The simple pendulum 297
10.6 Skills for analyzing processes involving vibrational motion 299
10.7 Including friction in vibrational motion 304
10.8 Vibrational motion with an external driving force 305
Summary 308 • Questions and Problems 309

11 Mechanical Waves 315
11.1 Observations: pulses and wave motion 316
11.2 Mathematical descriptions of a wave 318
11.3 Dynamics of wave motion: speed and the medium 321
11.4 Energy, power, and intensity of waves 324
11.5 Reflection and impedance 326
11.6 Superposition principle and skills for analyzing wave processes 327
11.7 Sound 331
11.8 Standing waves on strings 335
11.9 Standing waves in air columns 338
11.10 The Doppler effect 340
Summary 345 • Questions and Problems 346

12 Gases 352
12.1 Structure of matter 353
12.2 Pressure, density, and the mass of particles 356
12.3 Quantitative analysis of an ideal gas 361
12.4 Temperature 364
12.5 Testing the ideal gas law 368
12.6 Speed distribution of particles 373
12.7 Skills for analyzing processes using the ideal gas law 374
12.8 Thermal energy, the Sun, and diffusion 376
Summary 379 • Questions and Problems 380

13 Static Fluids 386
13.1 Density 387
13.2 Pressure inside a fluid 389
13.3 Pressure variation with depth 391
13.4 Measuring atmospheric pressure 395
13.5 Buoyant force 398
13.6 Skills for analyzing static fluid problems 401
13.7 Ships, balloons, climbing, and diving 403
Summary 407 • Questions and Problems 408

14 Fluids in Motion 415
14.1 Fluids moving across surfaces—qualitative analysis 416
14.2 Flow rate and fluid speed 418
14.3 Types of fluid flow 420
14.4 Bernoulli's equation 420
14.5 Skills for analyzing processes using Bernoulli's equation 424
14.6 Viscous fluid flow 428
14.7 Drag force 431
Summary 435 • Questions and Problems 435

15 First Law of Thermodynamics 441
15.1 Internal energy and work in gas processes 442
15.2 Two ways to change the energy of a system 445
15.3 First law of thermodynamics 448
15.4 Applying the first law of thermodynamics to gas processes 451
15.5 Specific heat 455
15.6 Phase change 458
15.7 Heating mechanisms 463
Summary 470 • Questions and Problems 471

16 Second Law of Thermodynamics 476
16.1 Irreversible processes 477
16.2 Entropy: the microscopic approach 480
16.3 Entropy: the macroscopic approach 484
16.4 Quantitative analysis of thermodynamic engines and pumps 488
Summary 495 • Questions and Problems 496

17 Electric Charge, Force, and Energy 500
17.1 Electrostatic interactions 501
17.2 Explanations for electrostatic interactions 504
17.3 Conductors and insulators (dielectrics) 507
17.4 Coulomb's force law 512
17.5 Electric potential energy 516
17.6 Skills for analyzing processes involving electric charges 521
17.7 Charge separation and photocopying 524
Summary 528 • Questions and Problems 529

18 The Electric Field 535
18.1 A model of the mechanism for electrostatic interactions 536
18.2 Skills for analyzing processes involving $\vec{E}$ fields 542
18.3 The V field: electric potential 546
18.4 Relating the $\vec{E}$ field and the V field 550
18.5 Conductors in electric fields 552
18.6 Dielectric materials in an electric field 555
18.7 Capacitors 558
18.8 Electrocardiography 563
Summary 565 • Questions and Problems 566

19 DC Circuits 572
19.1 Electric current 573
19.2 Batteries and emf 576
19.3 Making and representing simple circuits 578
19.4 Ohm's law 581
19.5 Qualitative analysis of circuits 586
19.6 Joule's law 589
19.7 Kirchhoff's rules 592
19.8 Resistor and capacitor circuits 596
19.9 Skills for solving circuit problems 600
19.10 Properties of resistors 602
Summary 608 • Questions and Problems 609

20 Magnetism 616
20.1 Magnetic interactions 617
20.2 Magnetic field 618
20.3 Magnetic force on a current-carrying wire 621
20.4 Magnetic force exerted on a single moving charged particle 628
20.5 Magnetic fields produced by electric currents 632
20.6 Skills for analyzing magnetic processes 634
20.7 Magnetic properties of materials 639
Summary 642 • Questions and Problems 643

21 Electromagnetic Induction 649
21.1 Inducing an electric current 650
21.2 Magnetic flux 654
21.3 Direction of the induced current 656
21.4 Faraday's law of electromagnetic induction 659
21.5 Skills for analyzing processes involving electromagnetic induction 662
21.6 AC circuits 668
21.7 Transformers 674
21.8 Mechanisms explaining electromagnetic induction 677
Summary 678 • Questions and Problems 679

22 Reflection and Refraction 685
22.1 Light sources, light propagation, and shadows 686
22.2 Reflection of light 689
22.3 Refraction of light 692
22.4 Total internal reflection 696
22.5 Skills for analyzing reflective and refractive processes 698
22.6 Fiber optics, prisms, mirages, and the color of the sky 701
22.7 Explanation of light phenomena: two models of light 704
Summary 706 • Questions and Problems 707

23 Mirrors and Lenses 712
23.1 Plane mirrors 713
23.2 Qualitative analysis of curved mirrors 715
23.3 The mirror equation 721
23.4 Qualitative analysis of lenses 725
23.5 Thin lens equation and quantitative analysis of lenses 730
23.6 Skills for analyzing processes involving mirrors and lenses 734
23.7 Single-lens optical systems 735
23.8 Angular magnification and magnifying glasses 739
23.9 Telescopes and microscopes 740
Summary 744 • Questions and Problems 745

24 Wave Optics 751
24.1 Young's double-slit experiment 752
24.2 Refractive index, light speed, and wave coherence 757
24.3 Gratings: an application of interference 760
24.4 Thin-film interference 764
24.5 Diffraction of light 768
24.6 Resolving power 772
24.7 Skills for applying the wave model of light 774
Summary 777 • Questions and Problems 778

25 Electromagnetic Waves 784
25.1 Polarization of waves 785
25.2 Discovery of electromagnetic waves 788
25.3 Applications of electromagnetic waves 793
25.4 Frequency, wavelength, and the electromagnetic spectrum 795
25.5 Mathematical description of EM waves and EM wave energy 797
25.6 Polarization and light reflection 802
Summary 808 • Questions and Problems 809

26 Special Relativity 813
26.1 Ether or no ether? 814
26.2 Postulates of special relativity 817
26.3 Simultaneity 818
26.4 Time dilation 819
26.5 Length contraction 822
26.6 Spacetime diagrams 824
26.7 Velocity transformations 827
26.8 Relativistic momentum 828
26.9 Relativistic energy 830
26.10 Doppler effect for EM waves 834
26.11 General relativity 838
26.12 Global Positioning System (GPS) 840
Summary 842 • Questions and Problems 843

27 Quantum Optics 847
27.1 Black body radiation 848
27.2 Photoelectric effect 853
27.3 Quantum model explanation of the photoelectric effect 859
27.4 Photons 864
27.5 X-rays 867
27.6 Photocells, solar cells, and LEDs 872
Summary 875 • Questions and Problems 876

28 Atomic Physics 880
28.1 Early atomic models 881
28.2 Bohr's model of the atom: quantized orbits 885
28.3 Spectral analysis 892
28.4 Lasers 897
28.5 Quantum numbers and Pauli's exclusion principle 899
28.6 Particles are not just particles 903
28.7 Multi-electron atoms and the periodic table 907
28.8 The uncertainty principle 910
Summary 915 • Questions and Problems 916

29 Nuclear Physics 921
29.1 Radioactivity and an early nuclear model 922
29.2 A new particle and a new nuclear model 924
29.3 Nuclear force and binding energy 928
29.4 Nuclear reactions 932
29.5 Nuclear sources of energy 935
29.6 Mechanisms of radioactive decay 939
29.7 Half-life, decay rate, and exponential decay 943
29.8 Radioactive dating 947
29.9 Ionizing radiation and its measurement 949
Summary 952 • Questions and Problems 953

30 Particle Physics 957
30.1 Antiparticles 958
30.2 Fundamental interactions 962
30.3 Elementary particles and the Standard Model 966
30.4 Cosmology 972
30.5 Dark matter and dark energy 974
30.6 Is our pursuit of knowledge worthwhile? 978
Summary 979 • Questions and Problems 979

Appendices
A Mathematics Review A-1
B Atomic and Nuclear Data A-11
C Answers to Select Odd-Numbered Problems A-15

Credits C-1

Index I-1